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DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary
BUREAU OF MINES
VAN. H. MANNING, Director

ECONOMIC METHODS OF UTILIZING WESTERN LIGNITES

BY

E. J. BABCOCK

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ECONOMIC METHODS OF UTILIZING WESTERN LIGNITES.

By E. J. Babcock.

INTRODUCTION.

EXTENT OF LIGNITE DEPOSITS.

The existence of vast deposits of lignite in the West Central and Western States is well known, although the extent and importance of the deposits have not been appreciated, nor has there been an adequate economic utilization of the deposits.

The work of the Bureau of Mines, the United States Geological Survey, and the State geological surveys is disclosing an increasingly large area, underlaid with this kind of coal. Among the States having the largest workable deposits may be mentioned North Dakota, Montana, Wyoming, Colorado, and Texas, and in several other Western States lignite occurs in smaller areas. In North Dakota alone it is estimated that the deposits cover approximately 32,000 square miles, many of them being 10 to 15 feet thick and capable of producing in all several hundred billions of tons of lignite.

When one stops to consider what these figures mean as to the immensity of these deposits in the West, it is not strange that people are seeking to ascertain better means for deriving larger benefits from the proper utilization of those great deposits. Consequently, any proposed methods of utilization that are promising are well worthy of careful consideration.

PURPOSE AND SCOPE OF THE INVESTIGATIONS.

The Bureau of Mines has been investigating more efficient methods of utilizing fuels, the pertinent reports issued by the bureau being given in the list at the end of this volume. In the State of North Dakota there has been begun at the college of mining engineering of the University of North Dakota, at Grand Forks, and at the mining substation, at Hebron, extended work on a variety of new and practical methods of using lignite. In this work special attention has been paid to the production of gas and its utility and economy for heating, lighting, and power purposes and the manufacture of briquets. In addition, many other improvements in methods of burning and utilizing lignite have been attempted. As the Federal Government controls great tracts of land underlain with lignite, it has a direct interest in the utilization of this fuel, and the Bureau of Mines, in its investigations of fuels belonging to or for the use of the Government, has cooperated in the study of lignite.

The purpose of this bulletin is to present a summary of the results thus far obtained in the work done at the college of mining engineering and at the mining substation of North Dakota, and to indicate the prospects that the results hold out for the future development of the lignite fields of the West.

What has been accomplished in this experimental work leads to the belief that great improvements can be made in the methods of utilizing lignite and in the manufacture of cheap gas for power and other purposes, and that the making of high-grade fuel briquets can be put on a commercially satisfactory basis. The result will be that not only will lignite be much more serviceable and much more generally used, but an immense quantity of slack and coal that would otherwise be wasted will be saved.

Furthermore, by the process described in this bulletin, large quantities of gas, especially valuable for power purposes, may be obtained at a low cost, as the work thus far carried on indicates that this gas can be used successfully with an internal-combustion engine for the production of electricity so as greatly to reduce the cost of power production and thus make possible a wide utilization of cheap electricity for industrial purposes.

CHARACTERISTICS OF WESTERN LIGNITES.

In order better to understand why these lignite deposits have not been developed more rapidly and to see what changes are needed to increase their value and usefulness, it is necessary at the start to consider certain general characteristics of lignite. Inasmuch as the work herein reported has been largely done at the school of mines and the mining substation of the University of North Dakota, most of the references and data here given are based on North Dakota lignite; however, the results of tests of lignites from several other States are presented.

Western lignites, from different localities, though in general similar, differ somewhat in both physical and chemical properties. Not only in different districts, but also in different mines, the composition varies considerably, especially in ash content, a matter of much importance in connection with the utilization of lignites. If the ash content of a lignite to be used in the production of gas is high, the ash content in the residue will be considerably increased through concentration in carbonization, and hence the residue will be less valuable for use in making briquets.

PHYSICAL CHARACTERISTICS.

Most Western lignites are brownish-black, few having much luster, but some samples approach, in appearance only, the duller varieties of cannel coal. In some districts, however, the seams are harder and more compact, and have a dark color and considerable luster. There is some difference in the character of the seams at different levels. Many of the upper deposits are too thin to be operated, and some are strikingly lignitic in color and structure, whereas the lower seams may be darker, more compact, and less friable. In many localities such seams might quite properly be classified as subbituminous coal, particularly some of the deposits in Montana, Wyoming, and Colorado. In many of these deposits, as in some of the North Dakota deposits, the lignite shows little or none of the woody structure characteristic of a true lignite, but in many of the Western deposits it is dark, semilustrous, and lacking in the physical characteristics of lignite, although the lignite character is revealed in chemical tests, in burning, usually in slacking, and in the character of the residue, the gas, and other by-products.

VARIATION IN COMPOSITION OF DIFFERENT COALS.

From a chemist's point of view it may be said that in a general way the quality of a coal depends largely on the proportions of fixed carbon, volatile matter, and ash. Coal consists chiefly of organic matter, but contains varying proportions of inorganic or inconbustible material—substances that were originally in the framework and sap of the plant, or were carried in as foreign material during the period of deposition. When coal is burned the organic matter is consumed and passes away as gas, but the inorganic part is left behind as ash. The relative proportion of the ash determines to a considerable degree the purity and the value of the coal. A coal that contains less than 5 per cent of ash may be considered as rather free from foreign impurities. Some bituminous and hard coals used contain 15 to 20 per cent of ash. If more than 10 per cent is found the coal may be considered impure; that is, mixed with foreign matter, generally in the form of clay which has worked its way into the deposit either during the period of deposition or after the accumulation of the coal.

SULPHUR CONTENT OBJECTIONABLE.

One of the most objectionable impurities in coals is sulphur, which is undesirable in almost all uses to which coal may be put. It tends to lessen the heating qualities of a coal and gives off obnoxious gases that corrode furnace grates and metallic surfaces in the flues. Most Western lignites, however, do not contain a large percentage of sulphur.

USUAL PROPORTIONS OF VOLATILE MATTER AND FIXED CARBON.

The combustible matter of coal is partly fixed (not easily driven off as gas), known as fixed carbon, and partly volatile, easily converted into gas. The fixed carbon corresponds to charcoal in wood, and in certain grades of bituminous coals is known as coke.

Most anthracite coal contains 80 to 90 per cent fixed carbon, is dense and hard, and has characteristic physical properties. Most semianthracite coal contains 70 to 80 per cent fixed carbon, whereas most bituminous coal contains 50 to 70 per cent fixed carbon. Many of the bituminous coals, rich in volatile matter, when burned in a retort produce a coke well adapted to manufacturing and metallurgical purposes. Most Western lignites do not contain more than 40 to 55 per cent of fixed carbon, and when burned in a retort the fixed carbon does not coke, but remains as somewhat shrunken and broken lumps of residue which, although rather high in calorific value, are of little value until briquetted into proper size and strength for use in stoves and furnaces, or under boilers.

AVERAGE COMPOSITIONS OF DIFFERENT WESTERN LIGNITES.

The results of many hundreds of analyses of lignite samples made under the direction of the writer indicate that the average composition of Western lignites when dry is about as follows: Fixed carbon, 51 per cent; volatile matter, 39 per cent; ash, 10 per cent. The moisture in the lignites as mined is 15 to 35 or even 40 per cent.

The average composition of North Dakota dry lignite is probably about as follows: Fixed carbon, 49 per cent; volatile matter, 43 per cent; ash, 8 per cent. The moisture in the lignite as mined is 25 to 35 per cent.

In a general way it may be said that 1 ton of Western lignite when dry will equal 0.4 to 0.7 ton of Eastern bituminous coal, the exact comparative values depending on the particular grades of lignite and of bituminous coal used for comparison.

EFFECT OF MOISTURE CONTENT OF LIGNITE.

Lignite, especially in large blocks as mined, breaks up easily when exposed to air. Such disintegration is no doubt due in large part to the rapid evaporation of water, which constitutes 20 to 35 per cent of most lignite as taken from the mines. The larger part of this moisture escapes rapidly and causes thereby checking and splitting of the lumps, eventually converting piles of lignite lumps into slack. This slacking is one of the greatest difficulties to be overcome in the commercial handling and utilizing of lignites and seems to be a general characteristic of the deposits throughout the West.

The cost of shipping coal containing so much moisture is high, and the moisture content causes a corresponding reduction in the efficiency of the fuel. It is, therefore, inportant that the moisture be removed before shipment. However the tendency of the coal to form slack when burned, even after the moisture has been removed, presents another difficult problem. As a result, the utilization of lignite has been confined to comparatively narrow regions near the deposits. The utilization of this coal would be enormously stimulated could it be satisfactorily and economically converted or concentrated into fuel free from moisture and of a size and strength adapted to general commercial uses; hence the development of some economical means of briquetting lignite is highly important.

THE PREPARATION OF LIGNITE FOR BURNING.

Lack of familiarity with the character of lignite and lack of knowledge of the best methods of burning it make many people unwilling to use this kind of coal. However, the use is gradually being extended as from time to time more perfect methods of burning appear.

MOISTURE CONTENT SHOULD BE REDUCED.

Improved methods of preparing lignite for the market have been developed and will no doubt sooner or later be adopted by mine operators. A universal mistake is made in burning lignite coal with too large a percentage of moisture. Most lignite when taken from the mine contains more than 25 per cent of moisture, which seriously interferes with the heating power of the fuel. If the lignite could be seasoned and broken into lumps of uniform small size before it is put on the market, the popularity and real value of the lignite would be greatly increased. Lignite that has been broken before drying does not slack as badly as when left to dry in large lumps. When the large masses dry the evaporation takes place from the surface and causes the masses to split into thin, small pieces. If the large lumps are first broken to about 3-inch size and then allowed to dry, the loss in slack is much reduced.

TESTS OF EFFECT OF ATMOSPHERIC DRYING.

In order to determine the possibility of removing any considerable proportion of the moisture from freshly mined lignite by exposure to atmospheric drying, and to determine also whether such atmospheric drying would cause any material loss of fuel value, a series of careful tests was performed. The tests were made with a pile of typical lignite taken directly from the mines and exposed to the effect of the air and weather for three weeks during the month of August. The coal was analyzed at the beginning and during the tests to determine the percentage of moisture, volatile matter, fixed carbon, and ash, and the heating value.

The determinations were made every third or fourth day. The records at the start and at the end of 14 days were as follows:

Results of exposure of lignite to weather.

Condition of lignite.	Moisture.	Volatile matter.	Fixed carbon.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
As mined	33.5	25.5	35	6
After 14-day exposure	12.52	34.83	46.05	7.6

In these tests there was a gradual decrease in the moisture until about 12.5 per cent was reached, at the end of about 14 days. Subsequently there was practically no further reduction in the moisture content. It would thus appear that in summer weather an exposure of freshly mined lignite for two or three weeks would materially reduce the percentage of moisture. There seems to be slight chemical change, and the heating value, as shown by numerous calorimeter determinations, is increased in proportion to the moisture removed. During this exposure the usual slacking occurred, but seemed to be much less when the coal while fresh from the mine was broken into small lumps.

LABORATORY TESTS OF EVAPORATIVE AND HEATING QUALITIES OF LIGNITE AND OF BITUMINOUS COAL.

In order to determine more perfectly by actual burning tests the effect of different kinds of treatment on the heating and evaporative power of North Dakota lignite carefully conducted laboratory stove tests were made. Average samples weighing several hundred pounds were taken from a number of mines, and the effect of differences in moisture content and in size of lump was studied. The results were compared with the results of similar tests of a high grade of bituminous coal, namely, a selected lot of screened Youghiogheny coal. The tests were made under exactly the same conditions and therefore permitted a close comparison with the sample of Youghiogheny taken as a standard. The idea of this test was not to determine the absolute theoretical heating power, but rather to determine by actual combustion in an especially arranged stove, in which conditions could be perfectly regulated, the heating and evaporative power of the lignite compared with the Youghiogheny standard. So far as the writer has been able to ascertain, no other such series of comparative stove tests of our lignites, combining the practical and scientific, has been made. The series mentioned furnished much and valuable information. There can be little doubt that the data will show nearly the relative heating value of the lignite coal as it is actually burned in the ordinary stove.

EQUIPMENT USED IN THE TESTS.

In order to carry on the tests in the most satisfactory manner, a special design of stove was procured. The stove was simple in construction and presented a large evaporative surface over which the reservoir for water-evaporation tests could be readily arranged. A sliding jacket or inclosure to prevent any modifying effects from the atmosphere of the room was provided.

The stove was set up in a small basement room. The tests were made in an inside room surrounded on all but one side by other rooms, a closely uniform normal or starting temperature being thus insured. The testing stove was connected with a chimney having a good draft, there being about 12 feet of pipe between the stove and the flue. The pipe was provided with two dampers to control the flow of air, and with a movable cap arranged for the introduction of a thermometer to determine the temperature of the flue gases and having provision for sampling the gases for analysis. Before each test the draft or flow of air through the stove and the temperature conditions where carefully regulated by means of an anemometer and thermometers arranged so as to give conditions that could be maintained practically the same for all the tests. The windows and the doors were kept closed during the tests. The temperature was taken at the start of each test by means of thermometers placed in different parts of the room. The temperature of the air in the dome above the water reservoir was taken as well as the temperature of the flue gases. Careful records of the temperature and of the weight of the water were kept.

MANNER OF CONDUCTING THE TESTS.

The fire was kindled with the same kind of material and the same quantity and in the same manner for every test. The same quantity of coal was weighed out each time. After a test had been started records were taken every 15 minutes while the fire lasted. The record showed the rise of temperature of the air of the room, the rise of the temperature of the air coming from the dome in which the water reservoir was placed, and the temperature of the flue gases.

After the first fire was out and the stove was cold, the water remaining was weighed and the total evaporation determined. The ashes were removed, weighed, and their percentage calculated. The ashes were then analyzed to determine the proportion of unconsumed combustible that they contained. The total number of degrees that the air of the room had been raised was then determined, and the total water evaporation from the reservoir was also determined, and from the results the relative heating and evaporative power of each sample of lignite was determined and compared with similar values for the standard bituminous coal used.

Some of the lignite was burned after having been broken to a size to pass a 2½-inch ring, being, therefore, about egg size. One set of samples from each mine was tested while containing the moisture remaining after shipment. Some tests were made of large lumps of lignite 6 to 10 inches in diameter. Other tests were made of egg-size lumps of lignite from which the moisture had been largely driven off. Before each lot of coal was placed in the stove average samples were taken and analyses made, to show the moisture, volatile matter, fixed carbon, and ash. The theoretical fuel value of each sample of lignite burned was calculated and compared with a similar estimate from the analysis of bituminous coal used as a standard. After the actual heating power based on the increase of air or room temperature and the amount of water evaporated had been ascertained, the theoretical and actual heating values of each sample of lignite were compared with similar values for the bituminous coal. An average of 16 of these stove tests of egg-sized lignite, its moisture content being the same as in the lignite as mined and marketed, showed about 50.6 per cent of the heating and evaporative value of the standard bituminous coal in a corresponding stove test. The average comparative heating and evaporative values of the egg-size dried lignite in the stove tests showed 65 to 75 per cent of the values obtained with the standard soft coal. Similar averages from the tests of the lignite burned in large lumps showed by the stove test about 40 per cent of the values of the standard bituminous coal subjected to the same tests.

RESULTS OF THE TESTS.

From these tests it was found that the theoretical values and the values indicated in the stove tests are fairly concordant. The highest heating power was shown by the dry coal and the lowest heating power was shown by the damp lignite when burned in large lumps. These facts are significant, as they show at once that there is considerable loss as well as great inconvenience in burning lignite in large lumps. The writer has long been convinced that lignite that is to be used in stoves should be broken at the mine to a comparatively uniform size, and it would seem that lumps of about 3 inches in diameter are about right for most purposes. Coal of this size is much more easily handled, and would therefore be more acceptable to the housewife for cooking and other domestic use. There is a great saving to the consumer in the use of dry lignite. Furthermore the coal burns so much more satisfactorily that it is better liked by the user, and as those not accustomed to the use of lignite coal always have some prejudice to overcome, the introduction of lignite would be greatly helped if it were dry and reduced to uniform and moderate size lumps. Such a change would be of service to the producers in popularizing their coal.

TABULATED DATA.

In order to show the system adopted in the comparative tests described, a part of the records is presented. Presentation of the full data from all of the tests does not seem warranted, but the essential results of the heating and evaporative tests of each coal and of the standard bituminous coal are presented in the following table, which also shows the composition of the coal as determined by chemical analyses:

Results of comparative heating and evaporative tests of lignite and bituminous coal.

Coal sample No.	Condition of coal.	Results of chemical analyses.				Results from burning fuel in direct-draft stove of special type.			
		Moisture in undried coal.	Proportions of constituents in dried coal.			Proportion of ash in air-dried coal.	Proportion of combustible remaining in ash.	Evaporative efficiency.	Heating efficiency.
			Volatile matter.	Fixed carbon.	Ash.				
		Per cent.	*Per cent.*	*Per ct.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	Large lumps, moist	32.5	38.7	54.7	6.6	7.7		36	53
3	do	32.0	38.1	54.2	7.7	17.8		31	
1	Egg size, moist	32.5	38.7	54.7	6.6	7.7	1.4	46	68
4	do	31.4	41.1	50.8	8.1		.9		60
3	do	32.0	38.1	54.2	7.7	9.7	1.1	41	70
3	Egg size, dry		38.1	54.2	7.7	12.9	3.0	59	
5	do		36.0	52.9	11.1		1.3	50	
6	do		35.0	46.8	18.2			54	87
	(a)	1.4	31.0	61.0	8.0	12.7	6.4	100	100

[a] Youghiogheny high-grade bituminous coal.

COMMENTS ON THE RESULTS.

These practical burning tests give much reliable information concerning the relative value of lignite. Although the results did not equal those with the high-grade bituminous coal used, still the heating-efficiency percentage was sufficiently high to show a fuel of much value.

The large size of the lignite as shipped from the mine is a cause of real difficulty in burning it in ordinary stove and heating plants. Lumps weighing 25 to 50 pounds are common in the lignite as marketed. There is practically no sizing, and the coal used for small heating stoves is supplied in as large lumps as that used for steam boilers. At the mines the coal should be broken by machinery and graded to the proper size for use in stoves, heating plants, and steam boilers. Persons who use lignite dislike to stop to break it when they are ready to use it. Too large lumps do not give sufficient oxidizing surface but give too open a fire body. A fire box properly filled with egg-size lignite gives a compact body of fire and still presents a much larger fuel surface than if the lumps are larger. Even for steam boilers much of the lignite shipped is in too large lumps. The coal prepared in smaller lumps is not only easier to handle but seems to stand weathering much better. It also seemingly gives much better economy in burning, even under boilers, than it does in the large lumps as they come from the mine.

Proper combustion of lignite depends largely on the use of a size of coal that will give an abundant air surface. Moreover, the stove should have a good draft so arranged that the air can be directed up through the burning coal, but so that it can easily be controlled and closely shut down when a low heat is desired. The fire box should be kept well filled with coal. Many persons fail to get good results because they do not have sufficient lignite burning to keep up complete combustion of the gases and do not properly regulate the drafts.

For steaming purposes there is no doubt but that great improvement could be made in the methods generally employed. Many firemen in using lignite quite overlook its peculiar physical and chemical characteristics, such as its tendency to slack in the fire box, its lack of density, its noncoking qualities, its high percentage of moisture, and its richness in light volatile gases, and endeavor to operate their furnaces much the same as they would in the use of ordinary bituminous coal. The result is a high fuel combustion, extra labor costs, and loss of boiler efficiency. But when the peculiar characteristics of lignite are carefully considered in the selection of boiler grates and combustion chambers, and in the methods of burning, a great saving can be effected.

A matter of fundamental importance in any successful method of using lignite is the proper consumption of the large volume of light volatile gases present in all lignites. In the ordinary furnace and boiler construction the heating power of a considerable proportion of these gases is insufficiently utilized or they pass out with the flue gases almost entirely unburned.

EXAMPLES OF EFFECTIVE UTILIZATION OF LIGNITE IN POWER-PLANT BOILERS.

USE IN ELECTRIC POWER PLANT.

An especially successful utilization of lignite and lignite waste was made by Mr. C. L. Larsen, chief engineer of the Hughes Electric Co., of Bismarck, N. Dak. Referring to the fact that many people do not economically burn raw lignite, Mr. Larsen says:[a]

> They have not learned the real value of lignite or how to obtain the best results. Some people will order a few sample carloads and before the fireman has used half a

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[a] In a communication to the author.

car of it he will condemn the coal, and, if the engineer has had no previous experience in burning lignite he will soon fall in line with the fireman, with the result that the lignite is rejected entirely.

LARGE LUMPS UNDESIRABLE.

Speaking further of the use of lignite, Mr. Larsen writes as follows:

To break up lump coal to 1-inch and 2-inch sizes requires too much time and labor for the fireman; nevertheless this is the size that gives the best results when used with a forced draft—but not as strong a draft as some people think who complain of not enough draft.

PROPER DRAFT ESSENTIAL.

The ideal furnace condition is that of supplying just the amount of air necessary for complete combustion of the fuel; and the combustion should be nearly complete in the furnace, which can not be done with natural draft.

I am very much in favor of a balanced draft. It may not be understood what is meant by a balanced draft; I will therefore explain it a little more thoroughly. A balanced draft is obtained by regulating the air pressure under the grates and the dampers in the smokestack to such an extent that the pressure in the furnace is the same as that of the outside atmosphere.

It is not easy to maintain a balanced draft as the thickness of the fire and the demand for more steam interfere with the adjustment of the dampers in the stack and the blast gates; but it is advisable to keep the draft as nearly balanced as possible for the reason that the fire doors must be opened rather frequently in burning lignite, and if the draft is too strong more air than is needed is supplied, and the excess air reduces the temperature of the furnace. This is proved by analyzing and taking the temperature of flue gases resulting from the use of a balanced draft. We can maintain from 14 to 16 per cent CO_2 and a flue-gas temperature of 450° F. But by opening the damper enough to produce a 12/100-inch water draft and then opening one of the fire doors, in a short time, less than 10 seconds, the CO_2 will drop to 9 per cent; this indicates that about 20 per cent excess air is admitted to the furnace.

IMPORTANCE OF HIGH TEMPERATURE IN FURNACE.

The temperature of flue gases is deceiving when lignite is being burned, as it burns much like wood.

In the burning of coal decomposition always precedes combustion; hence the greater the amount of volatile combustible contained in the coal the greater the flame volume and the greater the length of flame, and the probability of greater loss by the low temperature of the flame. As our lignite contains much volatile matter and is low in fixed carbon, an excess of air will rush the flame through the boiler and produce a low temperature of flue gases, also a low temperature in the furnace.

In order to obtain a high efficiency from lignite, a high temperature is required in the furnace, and this can be obtained by a suitable grate. I have found that a flat saw-dust grate with ½-inch round holes gives the best results. Such grates contain only 15 per cent air space, but by having small openings we can maintain a higher air pressure in the ash pit, and the air passes through the small holes and through the bed of fuel at a greater velocity, which produces a high temperature in the furnace, and as the volume is small, the heat is not rushed through the boiler and up the smokestack, but is absorbed by the water in the boiler, and a low temperature in the smokestack is obtained.

Under such conditions with a good boiler and setting a pound of lignite containing 35 per cent moisture, 6 per cent ash, and 7,000 B. t. u. will evaporate nearly 5 pounds of water per pound of fuel.

BOILER SHOULD NOT BE CROWDED.

Such results can be obtained when a boiler is not crowded above its rated capacity, say 3 pounds of water per square foot of heating surface, as we can not force a boiler much over its rated capacity with lignite.

It is therefore advisable not to burn lignite under boilers that are forced as can be done with good Eastern coal. We can force a lignite fire to burn 60 pounds of coal per square foot of grate surface per hour, and not make any more steam than when burning 50 pounds per square foot of grate surface, owing to the excess air which has carried away 10 pounds of coal per square foot of grate surface, or 70,000 B. t. u. with a boiler having 30 square feet of grate.

It will be seen that Mr. Larsen's statements of the methods he employs so successfully are well borne out by the data presented in the foregoing pages with reference to the characteristics of lignite and the proper methods of burning this fuel.

EXPERIMENTS BY RANDALL AND KREISINGER.

Some excellent investigations as to the proper use of lignite as a fuel for power-plant boilers were carried on by Randall and Kreisinger.[a] The conclusions reached were that for best results the lignite should be reasonably low in moisture and that the combustion chamber should be sufficiently large and of such construction that the light liberated gases should be retained and heated to combustion temperature before being permitted to pass out as flue gas.

For the tests mentioned a modification of the so-called Dutch-oven type, a sort of semiproducer style, was adopted. The author's investigations lead him to believe that some modification of this general type of combustion-oven construction is best adapted for the direct use of lignite for steaming purposes. A few extracts[b] from the report of the investigators mentioned will give a more comprehensive idea of the construction and operation of this type of boiler furnace and the results achieved. The extracts follow:

CONSTRUCTION OF FURNACE USED.

The most striking features in the construction of the furnace are the deep-set grate and the contraction of the space between the bridge wall and the end of the prolonged fire-brick arch. The grate is 21 inches below the lower edge of the firing door. The object of this construction is to enable the fireman to carry a thick fuel bed and still see its condition at the top. The side furnace door used in removing clinkers, is only 7 inches above the grate.

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[a] Randall, D. T., and Kreisinger, Henry, North Dakota lignite as a fuel for power-plant boilers: Bull. 8, Bureau of Mines, 1912, 42 pp., 1 pl., 7 figs.

[b] Randall, D. T., and Kreisinger, Henry, op. cit., pp. 7, 8, 40.

METHOD OF OPERATING FURNACE.

The furnace is designed to work on the gas-producer principle. The solid fuel is gasified on the grate and the gas passes through the space under the arch into the combustion chamber, where most of the gaseous combustible burns. The necessary air for combustion is added through the openings in the bridge wall. This air is preheated to 200° to 300° F. in coils and forced into the furnace under a pressure of 0.5 to 1 inch of water. Owing to the location and direction of these air openings, the air is blown in jets into the comparatively slow moving body of combustible gas, thereby causing considerable stirring, so that the gases and the air form a fairly homogeneous mixture. A small quantity of air is also added through the openings in the roof of the furnace. Although there is some combustion above the fuel bed, the greater part of the gases burns below the contracted arch and back of the bridge wall, after air has been added through the openings. With rate of combustion exceeding about 25 pounds of coal per square foot of grate the flames extend even into the space above the arch.

The furnace is equipped with a rocking grate consisting of two rows of grate bars. Each row is connected with two shaking levers in such a way that by shaking one lever alternate bars in the row are rocked. Each grate bar is supported by a 2-inch pipe, through which cold air circulates; the object is to keep the grate bars and the ash immediately above them cool, so that the ash will not fuse and adhere to the cold bars.

The combination of boiler and furnace setting described gives good results with North Dakota lignite. Steam can be made with a fuel efficiency of 55 to 58 per cent of the heat in the coal, and no difficulty is experienced in obtaining the full capacity of the boiler.

COMMENTS ON THE EXPERIMENTS.

The tests mentioned showed results closely similar to those obtained by others who have used somewhat the same type of furnace construction in the burning of lignite. It is, therefore, plainly evident that great improvement can be made in the ordinary results obtained in burning lignite under boilers. In the experiments alluded to the lignite was crushed to the size in which it would give the best results. Too large lumps do not give even oxidizing surfaces. In some places the surface is insufficient and in other places the fire body is too open. As has been previously stated, a fire box properly filled with egg-size lignite gives a compact body of fire and still presents a much larger fuel surface.

IMPORTANCE OF PROPER FIRING OF LIGNITE.

Proper combustion of lignite, as was stated in a previous paragraph, depends largely on using a size of coal that will give an abundant air surface, but in addition a good draft should be so arranged that the air can be directed through the burning coal to the best advantage and can easily be controlled and closely shut down when it is desired to hold the coal at a relatively low heat. The fire box should be kept reasonably well filled, but the firing should be done frequently by the application of thin layers of fuel to the surface of the bed of hot lignite. The ash and clinker should be removed carefully and at sufficient rate to prevent an accumulation of clinkers.

Many firemen fail to get good results in the use of lignite because of uneven firing. The fire is allowed to run low and then a large quantity of the lignite, much of it in large lumps and carrying a high percentage of moisture, is introduced. The large addition immediately slackens the fire and materially reduces the temperature in the fire box, and, by the formation of considerable vapor, reduces still further the temperature of the gases, the heat from which should be left for boiler absorption. By such firing it is impossible to keep a uniform load with a high boiler efficiency, and much loss of fuel is experienced. By using coal of reasonably small size and firing in thin layers frequently, this difficulty is reduced to a minimum.

Many details contribute to success or failure in the utilization of lignite, and the features mentioned should be kept well in mind in selecting boilers, grates, and combustion chambers as well as in the method of operating and firing.

USE OF PULVERIZED LIGNITE.

IMPORTANCE OF PROPER COMBUSTION.

There is little doubt that the most perfect combustion of highly gaseous coals like lignites could be brought about by burning the pulverized material in a properly constructed combustion chamber in a draft of air. Such a method, to a limited degree, has been employed with bituminous waste for years in connection with several industries in which large ovens are used, but the machinery and appliances required have hitherto been too large and costly to permit their general adoption in small heating or boiler plants. There seems no good reason why some satisfactory method of using lignite in this manner in small plants can not eventually be evolved. Pulverization of highly gaseous lignites produces fuel with properties closely similar to those of crude petroleum or crude gas; in fact, pulverized highly gaseous coal like dry lignite, when fed into a furnace with an air blast, gives very largely a gaseous fuel.

ADVANTAGES OF THE METHOD.

With the temperature of the furnace or combustion chamber once at the proper point, by means of valves the relative supply of coal and air can be regulated so quickly and so perfectly that nearly complete combustion of the heat-producing constituents can be obtained. Besides, with the proper equipment, the feed and the fire should be closely uniform, almost automatic, and requiring comparatively little work from the fireman. When dry pulverized lignite can be used in small boiler settings to advantage, there is no reason why it should not produce a relatively high heating efficiency, for, in a proper combustion chamber, besides the combustion of fixed carbon, this method would utilize nearly all of the volatile gases, which have high calorific power, a proportion of which is lost by the ordinary methods of combustion to which lignite is subjected.

PRODUCER GAS FROM LIGNITE.

PROGRESS IN THE PAST 10 YEARS.

For the production of power in moderately large plants, it is clear that lignite coal can be used to advantage by converting it into producer gas and using the gas in an internal-combustion engine. During the past 10 years considerable progress has been made in the adaptation of producer plants for the use of lignite, and the results obtained in commercial plants scattered over several of the lignite States, and in tests made by the Government, indicate that this method of utilizing lignite can be successfully and economically employed in many instances and that there is an opportunity for considerable expansion in the use of this type of power producer.

PRINCIPLE OF MAKING PRODUCER GAS.

Producer gas is derived from the incomplete combustion of a rather thick bed of fuel held in a specially devised combustion and gas-producing chamber. Unlike the production of ordinary coal gas, there is little or no residue of coke left in the producer, but the coal is in part converted into gas by the combustion of the remaining part. To bring about this transformation to the best advantage and to supply a larger amount of hydrogen and carbon monoxide, steam is commonly introduced into the chamber during the burning of the coal.

RESULTS OF GOVERNMENT TESTS AT ST. LOUIS.

During the World's Fair in St. Louis, a model producer-gas plant was put in operation by the United States Government. Surprisingly successful results in the production of power gas were obtained by the use of widely different coals. Arrangements were made for the testing of two or three carloads of North Dakota lignite at the plant. The results were most satisfactory. North Dakota lignite used in the producer plant gave an excellent grade of producer gas. Similar tests were made with lignites from other localities, and with a large number of samples of bituminous, anthracite, and other grades of coal.

TABULATED DATA.

The composition of producer gas varies greatly with the different fuels from which it is derived. The following table, made from the results of tests reported by Fernald and Smith,[a] gives for each of several different grades of coal the analysis and relative heating and power-producing quality and the comparative consumption of coal per unit of power produced by use in the steam engine and the producer-gas plant.

Results of gas-producer and steam-engine tests of different grades of coal.

Item.	Virginia semi-anthracite coal.	Ohio bituminous coal.	North Dakota lignite.	Texas lignite.	Colorado lignite.
Carbon dioxide, per cent	10.2	9.0	8.69	11.10	10.11
Carbon monoxide, per cent	19.1	20.2	20.90	14.43	17.38
Hydrogen, per cent	20.5	15.3	14.33	10.54	11.05
Methane (CH_4), per cent	1.9	2.7	4.85	7.48	5.00
Nitrogen, per cent	48.2	52.3	51.02	56.23	55.91
Ethylene (C_2H_4), per cent	0.1	0.5	....	....	....
Heat units per cubic foot of gas, B. t. u	160.7	165.2	164.1	169.7	149.0
Dry coal consumed by producer plant, per switchboard per horsepower-hour, pounds	1.29	1.44	2.29	2.22	1.71
Dry coal consumed in steam engine, per switchboard per horsepower-hour, pounds	4.46	3.97	6.47	7.45	4.85

ADVANTAGES OF MAKING PRODUCER GAS FROM LIGNITE.

Although it is true that, per cubic foot, the heat value of producer gas is low as compared with that of natural gas or coal gas, it being about one-fifth that of ordinary city coal gas, the volume of producer gas derived from a ton of coal is so large as to more than compensate for the difference in value. Because of the relatively large volume of gas produced, and the ease and cheapness of the process, the final cost per thousand feet of producer gas is low.

LIGNITE PRODUCER GAS IN TEXAS.

Lignite has been considerably used for producer-gas purposes in Texas. In this connection Phillips[b] says:

> During the past few years there has been a marked increase in the use of lignite for making gas in gas producers. The gas thus made is used for power in gas engines of special design, or for fuel for burning lime, etc. So far as known the gas is not used in Texas for burning brick, sewer pipe, tiling, etc., although it would certainly be well adapted for such purposes.
>
> There have been installed in this State 56 producers for making gas. * * * The success that has been reached in the smaller plants indicates the adaptability of the producer and gas engine to requirements varying from 50 to 250 horsepower, quite as well as to the larger uses.

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[a] Fernald, R. H., and Smith, C. D., Résumé of producer-gas investigations, Oct. 1, 1904, to June 30, 1910: Bull. 13, Bureau of Mines, 1911, pp. 108, 170, 174, 208, 212, 290, 292, 293, 294, 302, 304, 306.

[b] Phillips, D. McN., The use of producer gas in Texas: Univ. of Texas Bull. 189, 1911, pp. 59, 60, 61.

It is beyond question that a very active interest is now being shown in the use of producer gas made from lignite, and as experience is gained both in the handling of the various types of producers, and, more especially, in the design and construction of engines for using large volumes of gas of low-heating power, the use of lignite will be extended.

GENERAL VALUE OF PRODUCER GAS.

Fernald and Smith[a] have made a valuable and extensive report on producer-gas investigations. Pertinent abstracts[b] from their report follow:

The abundance of natural gas and the multiplicity of uses to which it has been applied have led to a much greater appreciation of the advantage of gaseous fuel, and have helped to emphasize the value of the gas producer. During the past few years there has been great development in the utilization of producer gas, not only for power purposes and in the manufacture of iron and steel, but in other industries as well.

SPECIFIC USES POSSIBLE.

Among the uses to which producer-gas fuel has been put are annealing, japanning, enameling, soldering, brazing, galvanizing, drying, evaporating, tempering, case-hardening, type casting, yarn singeing, heating molds, wash kettles, ladles, stoves, baker's ovens, and cooking. It has also been used rather extensively in brick, lime, and cement kilns, and in various types of ore-roasting furnaces.

RELATIVELY LOW-HEAT VALUE MUST BE CONSIDERED.

In using producer gas as a fuel one should remember that the heat value of the gas is low compared to that of the other gases used for similar purposes, with the exception of blast-furnace gas. Natural gas has an approximate average heat value of 1,000 B. t. u. per cubic foot; the heat value of artificial or ordinary city gas is about 650 B. t. u. per cubic foot; whereas the heat value of producer gas ranges from 100 to 275 B. t. u. per cubic foot, according to the method of production. This relatively low-heat value must be taken into account when considering the method of application. In spite of its low-heat value producer gas is usually cheaper for work requiring relatively large quantities of gas than any other fuel, with the possible exception of natural gas sold at a low price.

The introduction of producer-gas fuel for all types of service necessarily requires at the present time a certain amount of careful engineering promotion, owing to the uncertainty that exists regarding its successful use in fields in which natural or artificial gas or even solid fuels have been in vogue for years.

In many possible applications of producer gas as a fuel there seems to be little if any gain over direct firing with coal. Opinions differ regarding this point, many claiming that there is always a considerable saving in favor of producer gas. The difference either way is probably small, but other considerations are frequently of such importance as to give producer gas a great advantage. Under conditions requiring uniformity of temperature for continued periods, or variations in temperature at positive intervals, the ease with which the supply of producer gas can be regulated insures results that would be entirely impossible with solid fuel. Producer gas may also be employed with comparative ease as a reducing agent.

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[a] Fernald, R. H., and Smith, C. D., Résumé of producer-gas investigations. October 1, 1904, to June 30, 1910: Bull. 13, Bureau of Mines, 1911, 393 pp., 12 pls., 250 figs.

[b] Fernald, R. H., and Smith, C. D., op. cit., pp. 34, 35, 36.

Under the simple conditions required for boiler heating, it is questionable whether any advantage is to be obtained by the use of producer gas except, possibly, where low-grade fuels are burned. There are many fuels that can be utilized to advantage in the gas producer that can not be employed in direct steam-boiler firing.

GENERAL COMMENTS.

There are many advantages to be gained in converting low-grade fuel into gas when the uses to which it is to be put and other conditions will permit. Of course for many purposes such conversion can not be made, but for power and for many industrial purposes such gas has the advantage of being readily controlled, so far as the intensity and the application of heat are concerned, and it may be handled with little labor compared with that required when coal is used in the ordinary condition.

Producer gas from lignite would undoubtedly make a highly satisfactory fuel for use in burning brick and other clay products and, although it has not been so utilized to any great extent up to the present, it is, however, attracting the attention of the manufacturers of such products.

In 1910 it was estimated that 4 per cent of the producer plants in use were operating upon lignite. It is probable that the success thus far attained by these plants will soon stimulate a much more extensive use of lignite producer gas for certain types of power plants.

BRIQUETTED LIGNITE.

BRIQUETS COMPARED WITH OTHER FUEL.

At the present time undoubtedly by far the largest use of lignite is for domestic purposes—in heating plants, stoves, ranges, etc. For such use most of the lignite is supplied in sizes ranging from large lumps to pieces about the size of those in slack, careful sizing being employed rarely. The lignite is generally used in the most simple manner. Few special methods for burning or utilizing the lignite or for specially preparing it for the market have been adopted. However, there can be little doubt but that for most purposes, particularly for general stove and furnace use, briquetted lignite would be the most desirable form in which the lignite could be presented on the market; and lignite briquets of good quality and at a reasonable price should prove a most satisfactory and profitable fuel. Considerable success has been attained in the briquetting of both anthracite and bituminous coal wastes, and the lignites of Germany have been briquetted with some degree of success. But the briquetting of anthracite and bituminous coal waste is an entirely different problem from the briquetting of lignite, and the difficulties to overcome are comparatively simple. The German lignite also is of such character and composition that it can be briquetted with comparative ease. Furthermore, when binding materials are required for the German lignite, such materials and the labor necessary can both be obtained at a much lower cost in Germany than in this country.

However, the process briefly explained in the following pages is proving so successful in the experimental plant that there now seems little doubt but that if a briquetting plant, in conjunction with a gas-producing plant, is operated according to the principles and methods described a variety of by-products can be saved and utilized and that the residue, after the gas has been driven off, can be successfully briquetted into a concentrated and valuable fuel.

THE PRODUCTION OF LIGNITE GAS.

GASEOUS CONSTITUENTS OF LIGNITE EASILY DISTILLED.

Repeated experiments with lignite have made it clearly evident that lignite contains in addition to its high moisture content two widely different fuel constituents, namely, a large proportion of light gases, which pass off at a comparatively low temperature, leaving a residue in character between coke and charcoal, which requires a much higher temperature for combustion and burns more slowly than the lighter constituents. The residue does not coke, but remains as powder or slack, which checks the draft and is slow in oxidation. The gases, however, are volatile and are easily driven off from the coal at a comparatively low temperature. As a result they are distilled off quickly in the ordinary methods of burning and are either burned with a flashy flame or are lost, in a large degree unconsumed, with the flue gases. Thus there is an uneven combustion of lignite, and it is impossible with the ordinary type of furnace and fire box to obtain a high degree of efficiency in its consumption.

PRELIMINARY LABORATORY EXPERIMENTS.

The first work in a systematic research as to the production of gas from lignite coal and the utilization of the by-products was of a preliminary nature. It was carried on in a small way with laboratory apparatus in testing a large number of lignite and ordinary gas coals for the purpose of obtaining a general idea of the comparative quality and character of the gas, tar, and residue produced by each of the coals, of the temperature required for most efficient work with the various coals, and of the probable amount of ordinary by-products obtainable from each under the conditions employed.

The lignite samples, collected from different areas by the author and his assistants, were subjected to a great variety of preliminary tests.

This work required much time and labor, but gave most valuable information which was utilized in planning the later and more systematic attacks on lignite-gas problems. The results proved conclusively that the gas from the lignites of different deposits is closely similar, that it may be removed at nearly the same temperature, and that a residue and by-products of a general similarity are left although the quantity of each varies considerably. The main products and by-products thus obtained were compared with those obtained from ordinary gas coals tested by the same processes. All of this preliminary work was most suggestive as to the possibility of the profitable production of lignite gas.

EXPERIMENTAL-LABORATORY EQUIPMENT.

The next step in the investigation was the designing and erection of a small working lignite plant adapted to laboratory methods but of sufficient size to approximate more closely the methods that might ordinarily be used in the manufacture of gas from lignite.

The plant was constructed and operated as follows:

A cast-iron retort is arranged so as to form a small gas bench similar to that ordinarily used in gas works. The retort has a capacity of about 40 pounds at a charge and is heated by a coal-fired bench. The retort is fitted for pyrometer tubes, and readings are taken constantly during each run.

Provision is made for running small charges of coal by the use of a small furnace and retort. For special purposes when it is desirable to use a still smaller quantity of coal a second smaller retort is used. This has a capacity of 5 pounds of coal. By a system of connections and valves either the large or the small retort can be by-passed. The main connection leads from either retort to the tar extractor, which serves to collect those products that condense the most readily at higher temperatures. The extractor consists of two cones so arranged that the gas must whirl around the inside cone before reaching the outlet; the condensed material is gradually drawn to a point where it is delivered to a small cylinder provided with a full-way valve for completely discharging the tar and other condensed matter into a measuring cylinder.

From the extractor the gas passes to the condenser, which consists of tubes arranged to drain to the lowest section and provided with a valve for discharging. The condenser tubes are surrounded by circulating water. Beyond this is the scrubber provided with a sprayer, coke trays, etc. From the scrubber the gas passes to the purifier, which is provided with two sets of purifier compartments so that the gas can be made to pass through either one or both sets of compartments. One set is fitted with lime for removing carbon dioxide, and the other set is supplied with iron oxide. An exit pipe leads from the purifiers to the gas holder, which is a large size meter prover, with a capacity of 10 cubic feet. This prover or gas holder is carefully calibrated and provided with an accurately graduated scale indicating the contents in cubic feet and hundredths of a cubic foot. The holder is arranged to supply any pressure desired and to give a uniform pressure with any quantity of gas. It is provided with thermometers, pressure gages, etc. From the holder the gas is piped to the gas-testing laboratory, on the floor directly above the gas plant. In this laboratory are made the chemical analyses and also a great variety of practical burning tests for heat and lighting qualities. The calorific tests are also made here by the use of a standarized gas calorimeter.

SPECIALLY DESIGNED PLANT.

The small plant just described, at the University of North Dakota school of mines, at Grand Forks, N. Dak., was the forerunner of the larger specially designed briquetting and gas plant at the mining substation at Hebron, N. Dak. (Pls. I and II), where both briquetting and gas problems are being worked out on a scale so large as to insure results applicable to commercial practice. The briquetting press is capable of turning out 2 tons of briquets per hour, and the gas plant is a full-size unit, complete, and of the standard type of construction.

The equipment of the large experimental gas plant at the mining substation consists of a bench of one retort, one condenser, one exhauster, two scrubbers, one purifier, and one meter, all of the full size used in commercial plants, and one gas holder and miscellaneous apparatus necessary for the proper operation of the plant.

The gas bench is substantially constructed. Its dimensions are 11 by 6½ by 7⅔ feet. The foundation, 1 foot thick, is built of common brick.

The bench contains one standard clay retort 1¼ by 2⅙ by 9 feet.

The retort is 4 inches thick throughout, with the exception of the head, which is made heavier and thicker to receive the mouthpiece. As the retort is the standard size used in gas works, it is capable of carbonizing about 400 pounds of coal in four hours, with a retort temperature of 1,200° to 1,800° F.

The bridge wall is in the center of the bench and extends from the bottom of the firebox to the top of the retort. The wall is 9 inches thick, and is built of fire brick. It causes the gases from the furnace to burn upward around the retort in the front end of the bench and downward in the rear end. Hence the top and bottom of the retort are heated equally and an even temperature is obtained. The retort is provided with a cast-iron self-sealing mouthpiece 15 by 26 inches.

The chimney is 9 by 13 inches and is placed at the back of the bench. It extends from the lower combustion chamber, underneath the retort, to the top of the bench. Near the bottom of the chimney is a damper, by which the draft can be regulated. A steel stack 15 feet high surmounts the chimney and extends through the roof of the building.

The hydraulic main consists of a 2-foot length of 32-inch pipe. The ascension pipe from the retort is connected with the dip pipe of the hydraulic main by a 10-inch tee. On the opposite side of the main is a 4-inch outlet service to the condenser.

Attached to one end of the hydraulic main, and connected with it by an elliptical opening, is a 15-inch, cubical, cast-iron box. This box is provided with a tar-drain regulator and a drain-water connection to a water gage.

The tar-drip regulator is of special design and can be regulated so that the hydraulic main can be operated without a water seal, or with any desired seal up to 4 inches.

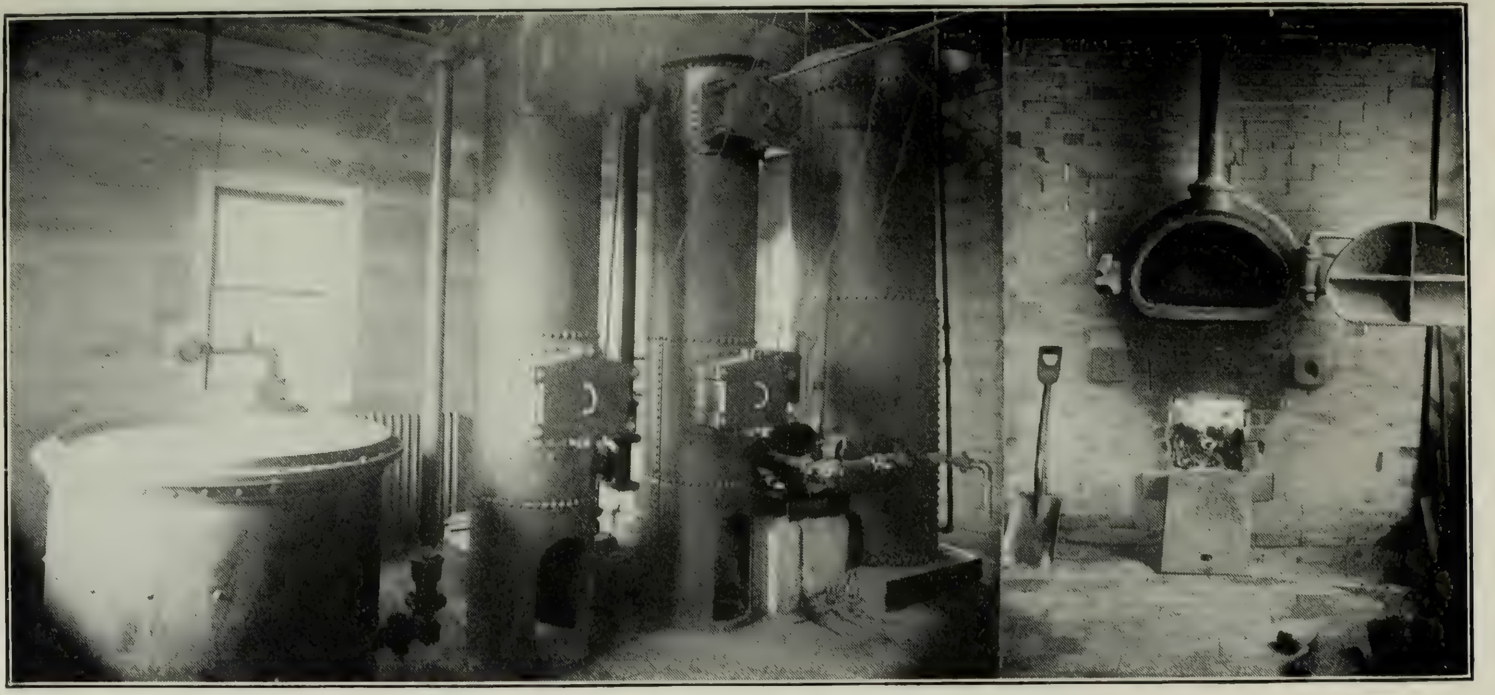
In the bottom of the box, and at the lowest point in the hydraulic main, is a 2-inch outlet pipe. This pipe can be opened or closed by a valve and is connected with the tar barrel. By means of this drain all the tar and ammoniacal liquor can be drained out of the hydraulic main after each experimental run. The advantage of this arrangement is that fresh water can be used on each new charge, and the danger of accumulated tar absorbing illuminants from the gas is avoided. Further, the products from each experiment can be accurately weighed and determined.

A standard water-tube condenser is used to remove the tar, coke dust, and pitch, and to condense the superfluous water vapor. The condenser is 3 feet in diameter by 11 feet high, and it contains 21 water tubes 3 inches by 8 feet.

The cooling water enters the base of the condenser and flows upward through the tubes into the reservoir at the top, which is provided with an overflow pipe that leads into a sump outside the building. The supply of water to the condenser can be regulated so that the gas can be cooled to any desired temperature above that of the inlet water.

The gas enters the condenser through a 4-inch tube and passes downward around the water tubes to the outlet at the bottom. The water flows in a direction opposite to that of the gas, so that by the time it reaches the inlet of the condenser it has, by absorbing the heat of the gas, attained a comparatively high temperature, and thus any sudden cooling of the gas at the entrance is avoided.

The bottom of the condenser is provided with a 2-inch tar outlet, through which the tar, ammoniacal liquor, etc., can be discharged into a tar tank.



PART OF LIGNITE-GAS PLANT AT EXPERIMENTAL SUBSTATION AT HEBRON, N. DAK.

The exhauster is a No. 1 Root and is provided with a 3-inch gas inlet and outlet. It consists of a vertical steam engine direct connected to the exhauster and mounted on a heavy cast bedplate.

The speed of the exhauster can be made to vary in accordance with the volume of gas being generated in the retorts. The speed is regulated by an automatic steam valve which permits uniform pressure at whatever gage desired.

Two cylindrical tower scrubbers are used to remove the last traces of tar, ammonia, and other impurities. The scrubbers are constructed of sheet steel three-sixteenths of an inch thick and are 24 inches in diameter by 8 feet high. The scrubbers are filled with wooden trays, supported on a steel angle ring.

The liquor used in the scrubber is admitted into the head through a 1-inch pipe, and is distributed equally over the surface of the tray by a sprayer. Fresh water, sprayed into the top of scrubber No. 2 by an overhead flushing apparatus, absorbs practically all the ammonia remaining in the gas, which enters from below and flows into a 100-gallon ammonia-liquor tank; from here the weak liquor is lifted by a centrifugal pump to the top of scrubber No. 1 to thoroughly wet its filling material. The liquor from scrubber No. 1 also passes by a trapped drain into the ammonia sump, and thus there is a continuous circulation of weak liquor. The top of the ammonia tank is well covered to prevent loss of ammonia by evaporation. By this process a part of the carbonic acid and sulphuretted hydrogen, as well as other sulphur compounds, are removed, the lime and oxide purifiers being thus relieved; the weak liquor is also brought to the requisite commercial strength.

The purifier is used to remove, or reduce to a negligible quantity, the carbonic acid and sulphuretted compounds in the gas. It is a sheet-steel, cylindrical box 4 feet in diameter by 2½ feet deep and is provided with 3-inch inlet and outlet gas pipes. The purifying material is supported on wooden trays. The purifier has not been used much on the gas produced from lignite, for although the gas is high in carbon dioxide it is nearly free from sulphur. The purification, however, materially raises the heat value of the gas.

An accurate meter is used to measure the volume of gas generated in each experimental run.

The gas holder consists of a holder 9¾ feet in diameter by 13½ feet deep, erected in a steel tank 10¾ feet in diameter by 13 feet deep. This holder is accurately calibrated and thus serves to check the meter readings.

The pressure of the gas can be conveniently taken in any part of the plant by a central differential gage 24 inches high and provided with a scale graduated to tenths of an inch. It is connected with the various parts of the plant.

The appliances for taking the temperature and pressure of the gas are arranged so that the operator can, by throwing a switch, read at his desk the temperature or pressure at any part of the plant. This arrangement is not only convenient and a saving of labor, but it is helpful in accurate scientific work.

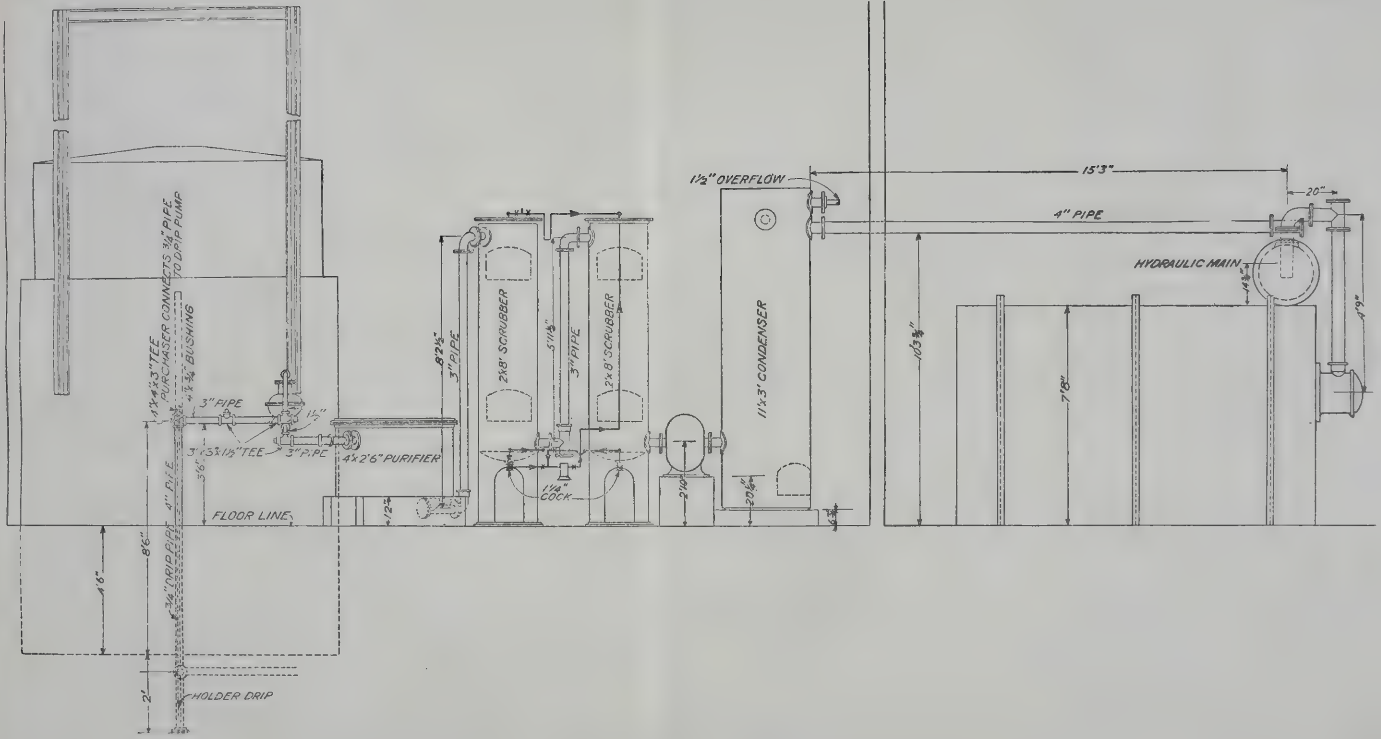
GENERAL RESULTS OF EXPERIMENTAL WORK.

The large number of experiments performed during the progress of the work in the laboratory and in the plant just described indicate that one of the methods offering the greatest possibility in the utilization of lignite is that of producing gas in a retort and utilizing the retorted residue and by-products. In carrying out this process, four products are obtained. First, in the use of comparatively dry lignite a large yield of gas is procured, the gas being of a quality adapted for power and for heating and lighting purposes. Second, after the gas has been driven off the lignite is converted into a noncoking residue of good quality, having a high percentage of fixed carbon and excellent heat-producing properties. Third, a tar is obtained which, with proper distillation or concentration, gives a product promising to be of considerable commercial value. The preliminary experiments thus far carried on would indicate that by special treatment the tar can be advantageously used in the process of briquetting. It also contains other products of evident worth. Fourth, a product is derived containing a large yield of ammonia which, after being converted into ammonium sulphate, may have considerable market value.

During the tests of the past two years careful observations were made to determine the temperature required, the amount of gas produced, the amount of coal residue left, and the quantity and character of tar and ammonia by-products. Careful analyses and calorific determinations of the gas were then made. In this manner much valuable information has been procured. The amount and character of the gas obtained from lignite has been rather surprising and very encouraging. Indeed, there seem to be great possibilities in the manufacture of gas from lignite, especially if all of the by-products are carefully utilized.

PROCEDURE IN EXPERIMENTS.

The lignite used for experimental work was gathered from many mines included in a wide area in the State of North Dakota, and from mines in Montana, Wyoming, Colorado, and Texas. The samples were procured in considerable quantities and were carefully analyzed and air dried to various degrees before being used in the gas plant. In addition to the tests of lignite, runs were made on



ELEVATION OF PLANT FOR PRODUCING GAS FROM LIGNITE AT EXPERIMENTAL SUBSTATION AT HEBRON, N. DAK.

other kinds of bituminous gas-producing coals to permit a comparison as to operating results and the products procured. By the use of samples from so many districts equitable average results were obtained.

The type of construction of the gas plant permitted its being operated in a manner closely similar to that employed in many commercial gas plants. Every step of the operation was carefully watched and made to approach as nearly as possible the methods that might ordinarily be expected to be required for economic production. The quality of gas produced by the plant is probably inferior to that which could be procured in a large commercial plant, owing to the fact that in stopping and starting and carrying on the experimental work there is frequently introduced into the retorts, apparatus, and pipes varying amounts of air—a condition that can not be eliminated in an experimental plant. Consequently, the gas contains an unduly large proportion of carbon dioxide and of residual air.

Nevertheless, the plant has given excellent results and, as regards the amount and quality of gas that can be derived from lignite coal, indicates much wider possibilities than were expected. There was generally used for each charge of the retort 400 pounds of air-dried coal, the moisture content of which was definitely known. The coal was crushed to an average size which would pass through a 2-inch ring. The lid of the retort was well clamped and sealed, and the temperature raised gradually to the required degree. A series of experiments was conducted to determine the temperature giving the largest quantity and the best quality of gas. It was found that the gas distilled freely at 900° to 1,000° F., whereas the proper temperature to give the maximum quantity and quality of gas seemed to be between 1,200° and 1,400° F. High-temperature readings were made by the pyrometer, along with simultaneous records of the rate of gas production. At frequent intervals gas samples were obtained for analyses. The desired heat was carefully maintained until the evolution of gas ceased, after which the valves were closed, the retort was cooled, and the noncoking residue was cooled and carefully weighed. The gas was passed successively through the tar extractor, the condenser, the scrubber, the purifier, and finally to the gas holder, where the quantity was accurately read off from a scale connected with the holder, careful corrections to normal temperatures and barometric pressure being made.

After the gas had been measured and analyzed and had been tested in the calorimeter to determine its heat value, it was used with different types of burners and in various practical ways to demonstrate its efficiency as a fuel gas. As regards the by-products, the tar was separated from the water and weighed and the ammonia was separated and its quantity determined. The resulting proportion of noncoking retort residue remaining was also determined, and an analysis was made to ascertain the percentages of fixed carbon, volatile matter, and ash. By the use of such data the composition of the residue could be compared with that of the original lignite and also with that of bituminous and anthracite coal.

The methods of coal and gas analysis employed were those adopted by the fuel-testing section of the United States Bureau of Mines and in the best practice by gas experts. The calorimeter determinations were made with a properly standarized gas calorimeter.

TABULATED DATA.

The following tables give average results of tests of a large number of widely different but representative coals. The greater number of the tests were made with North Dakota lignites from various parts of the State, but lignites from Montana, Colorado, and Texas were also represented.

Gas yields and heating values of representative lignite samples.

Sample No.	Unpurified gas.		Retort temperature.
	Yield per ton of air-dried lignite.	Calorific value.	
	Cubic feet.	*B. t. u.*	*°F.*
1	12,298	363	1,700
2	11,676	348	1,500
3	13,297	285	1,600
4	13,108	384	1,600
5	11,692	392	1,720
6	11,770	372	1,650
7	10,300	392	1,500
8	12,835	390	1,560
9	10,663	401	....
10	11,306	407	1,510
11	11,801	400	1,540
12	12,525	379	1,510
13	12,803	382	1,510
14	12,160	387	1,385
15	9,759	404	1,430
16	10,877	385	1,580
17	9,335	435	1,360
18	10,160	415	1,270
19	9,460	420	....
20	11,730	411	....
21	9,124	425	1,764
22	8,368	434	1,300
23	9,623	476	1,200
24	11,450	334	1,650
25	7,825	487	1,110
Average	11,038	396	1,498

Results of analyses of gas from representative lignite samples.

Sample No.	Illuminants.	Carbon monoxide.	Hydrogen.	Ethane.	Methane.	Nitrogen.	Oxygen.	Carbon dioxide.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.90	23.85	43.90	0.16	13.88	8.76	0.75	7.80
2	1.00	25.56	44.55	.90	7.06	15.43	4.00	1.50
3	1.30	19.85	38.78	.33	12.78	13.26	1.90	11.80
4	.65	28.02	45.07	.73	13.83	4.70	.30	6.70
5	.55	25.02	44.00	.00	11.83	10.90	1.00	6.70
6	2.27	17.49	46.34	.00	15.89	3.67	.55	13.79
7	1.80	23.61	44.12	.29	8.80	13.88	2.78	4.72
8	2.55	17.00	50.30	.16	13.52	5.59	3.03	7.85
9	2.15	22.45	47.63	1.79	10.41	5.27	.95	9.35
10	1.85	22.70	43.61	.09	15.67	5.28	.90	9.90
11	1.45	27.75	41.85	.15	10.44	7.11	.85	10.40
12	2.25	21.75	40.26	.81	12.72	3.76	.45	18.00
13	1.30	20.44	27.11	.16	13.18	22.16	5.55	10.10
14	2.35	19.15	40.60	.00	14.55	11.55	1.35	10.45
15	1.20	14.05	14.10	.13	10.50	42.27	10.50	7.25
16	.75	21.13	28.24	.24	16.72	14.62	1.30	7.00
17	3.38	20.61	38.52	.00	19.72	3.28	.95	13.53
18	2.60	12.80	43.70	.00	23.10	9.40	1.70	6.70
19	.65	22.34	45.99	1.55	13.13	5.59	1.10	9.65
20	1.70	17.90	44.60	.00	16.60	4.80	.30	14.10
21	.80	9.95	32.93	.00	31.62	.40	2.10	22.20
22	3.40	14.70	40.00	.00	19.90	8.80	1.40	11.80
23	3.10	15.30	41.70	.00	18.10	7.40	1.10	13.30
24	3.60	18.20	36.10	.00	19.20	8.50	.60	13.80
25	3.38	20.61	38.53	.00	19.72	3.28	.95	13.53
Average	1.88	20.09	40.10	0.30	15.31	9.98	1.86	10.48

Residues yielded by representative lignite samples.[a]

Sample No.	Yield per ton of coal as charged.	Proportion of lignite charged represented by residue yield.	Sample No.	Yield per ton of coal as charged.	Proportion of lignite charged represented by residue yield.
	Pounds.	*Per cent.*		*Pounds.*	*Per cent.*
1	1,078	53.90	15	1,066	53.30
2	1,071	53.55	16	1,085	54.25
3	1,035	51.75	17	1,208	60.40
4	1,137	56.85	18	1,046	52.30
5	1,129	56.45	19	1,198	59.90
6	1,140	57.00	20	891	44.55
7	1,161	58.05	21	1,236	61.80
8	1,051	52.55	22	1,081	54.05
9	1,137	56.85	23	1,140	57.00
10	1,130	56.50	24	1,000	50.00
11	1,108	55.40	25	870	43.50
12	1,103	55.15			
13	1,110	55.50	Average	1,092	54.60
14	1,078	53.90			

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[a] The samples were partly air dried, containing 8 to 27 per cent moisture.

Calorific values and results of analyses of lignite residue.

Sample No.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Calorific value per pound of residue.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*B.t.u.*
1	1.91	5.87	74.71	17.51	1.54	11,738
2	8.38	6.97	62.93	21.72	2.88	10,055
3	.31	9.86	74.67	15.16	1.48	12,207
4	.00	6.48	73.86	19.66	1.53	11,149
5	2.03	6.60	75.20	16.17	1.45	11,506
6	.57	7.88	72.38	19.17	2.27	11,399
7	.00	8.08	75.46	16.46	1.91	11,681
8	.00	9.45	74.00	16.55	1.93	11,589
9	.00	9.20	73.20	17.60	3.04	11,558
10	.00	8.60	73.84	17.56	2.49	11,618
11	.00	8.09	74.58	17.33	2.09	....
12	.00	9.00	72.96	18.04	2.06	....
13	1.68	7.04	73.88	17.40	....	....
14	4.90	8.76	67.19	19.15	....	....
15	1.85	10.64	69.78	17.73	....	....
16	.80	3.10	75.95	20.15	1.27	9,740
17	.00	15.85	74.30	9.85	....	12,905
18	.00	.90	90.50	8.60	....	....
19	.00	4.11	77.25	18.64	....	12,820
20	.00	12.70	77.05	10.25	....	11,940
21	.35	8.05	80.60	11.00	....	12,240
22	.00	7.00	81.40	11.60	....	12,442
23	.00	7.97	85.19	6.84	....	15,035
24	.00	15.07	68.80	16.13	....	11,451
25	2.15	2.01	78.34	17.50	1.79	....
Average	1.00	7.57	75.52	15.91	1.98	11,838

Average results of gas tests of 10 North Dakota lignite samples.

	Per cent.
Analysis of coal:	
Moisture in lignite as received (partly dried)	6.98
Volatile matter (partly dried)	39.50
Fixed carbon (partly dried)	44.64
Ash (partly dried)	8.88
Heating value of lignite (partly dried), B. t. u. per pound, 10,160.	
Yield of unpurified gas from partly dried lignite, cubic feet per ton, 12,487.	
Analysis of unpurified gas:	
Illuminants	1.49
Carbon monoxide	22.52
Hydrogen	44.44
Methane	12.84
Ethane	.36
Nitrogen	7.88
Carbon dioxide	9.15
Oxygen	1.32
Residue yield from partly dried coal	55.34
Analysis of dry residue:	
Volatile matter	7.99
Fixed carbon	73.97
Ash	18.04
Heating value, B. t. u. per pound, 11,710.	

Average results of gas tests of four Montana lignites.

Analysis of lignite:	Per cent.
Moisture in lignite as received	9.55
Volatile matter in dry coal	38.20
Fixed carbon in dry coal	44.90
Ash in dry coal	16.90
British thermal units per pound (coal as received), 8,675.	
Yield of unpurified gas from lignite as received, cubic feet per ton, 10,243.	
Analysis of unpurified gas:	
Illuminants	3.2
Carbon monoxide	16.2
Hydrogen	40.0
Methane	21.8
Nitrogen	7.3
Oxygen	1.0
Carbon dioxide	10.5
Heating value, B. t. u. per cubic foot, 445.	
Yield of residue from lignite as received	57.8
Analysis of dry residue:	
Volatile matter	5.3
Fixed carbon	72.0
Ash	22.7
Heating value, B. t. u. per pound, 9,740.	

Average results of gas tests of Colorado lignites.

Analysis of lignite:	Per cent.
Moisture in lignite as received	17.2
Volatile matter in air-dried lignite	36.38
Fixed carbon in air-dried lignite	57.74
Ash in air-dried lignite	5.88
Heating value of lignite as received, B. t. u. per pound, 10,348.	
Yield of unpurified gas from lignite as received, cubic feet per ton, 8,746.	
Analysis of unpurified gas:	
Illuminants	3.20
Carbon monoxide	14.25
Hydrogen	40.90
Methane	19.95
Nitrogen	7.10
Oxygen	1.05
Carbon dioxide	13.55
Heating value, B. t. u. per cubic foot, 429.	
Yield of residue from lignite as received	53.78
Analysis of dry residue:	
Volatile matter	.9
Fixed carbon	90.5
Ash	8.6

Average results of gas tests of three Texas lignites.

Analysis of lignite:	Per cent.
Moisture in lignite as received	11.15
Volatile matter in air-dried lignite	44.90
Fixed carbon in air-dried lignite	44.99
Ash in air-dried lignite	10.11
Heating value of lignite as received, British thermal units per pound, 9,943.	

Yield of unpurified gas from lignite as received, cubic feet per ton, 10,557.

Analysis of unpurified gas:

	Per cent.
Illuminants	1.53
Carbon monoxide	16.94
Hydrogen	39.26
Methane	18.85
Nitrogen	6.56
Oxygen	.43
Carbon dioxide	16.43

Heating value, British thermal units per cubic foot, 335.

Yield of residue from lignite as received	52.11

Analysis of dry residue:

Volatile matter	6.76
Fixed carbon	75.94
Ash	17.30

Heating value, British thermal units per pound, 12,836.

COMMENTS ON TABULATED DATA.

The results presented are typical of those from several hundred tests conducted. During the work several hundred tons of lignite was carbonized, and probably 1,000,000 to 2,000,000 cubic feet of lignite gas was produced.

It has been necessary, from start to finish, to develop the whole process for the treatment of lignite. During the work many peculiarities of lignite, lignite gas, residue, and by-products, as well as peculiarities and difficulties in the adaptation of the process of treatment have been encountered and in a great measure overcome. The method evolved seems to be thoroughly practical and to possess many commercially attractive features.

TEMPERATURE OF CARBONIZATION.

IMPORTANCE OF DISTILLATION TEMPERATURE USED FOR ANY COAL.

In the production of gas from coal, whatever the variety of coal used and whatever the type of retort or oven in which the gas is generated, the temperature required and the time necessary to remove the gas are important practical considerations. Not only is there a great difference in the products derived at different temperatures, but there is also a great difference in the necessary cost of operation.

Because the length of life of the retorts or ovens is rapidly reduced as the temperature to which they are subjected is increased, and because the operating expenses are greatly increased by the necessity of high-temperature distillation, it is a matter of double consequence to procure materials and to use methods that will permit a high degree of carbonization at as low a temperature and in as short a period as is consistent with the recovery of gas and by-products of satisfactory quality.

In the production of gas from ordinary bituminous coals there has been considerable discussion among practical and technical authorities as to the relative merits of high and low temperature distillation. It may be said that products of somewhat the same characteristics as those obtained in the treatment of bituminous coal are met with to a certain degree in the treatment of lignite, but the conditions necessary for obtaining the best results in the carbonization of lignites are widely different from those demanded for bituminous coal. Much of the lignite as mined contains 30 to 35 per cent moisture. The question that immediately rises is as to the effect of this moisture on the gases, residue, and by-products and also on the time and temperature required for carbonization.

INFLUENCE OF MOISTURE CONTENT OF LIGNITE ON TEMPERATURE OF DISTILLATION.

In the experiments it was quickly found that in the use of the ordinary gas retort of standard size the large proportion of water in the lignite immediately reduced the retort temperature, thereby delaying the time at which the distillation of gas began, and at the same time additional fuel and labor were required to bring the retort temperature back to the heat required for carbonization; thus there was an immediate loss of time, fuel, and labor in the use of lignite with its normal moisture content, and unless the yield of gas and by-products in quantity or quality would repay for the losses it was evident that it would be advisable to at least partly dry the lignite before introducing it into the retort. Accordingly many experiments were performed to ascertain the yield and quality of gas and the residue and by-products recovered from the distillation of lignite with the moisture content as high as when mined.

The results of the investigations indicate clearly that, as explained later, the proper retort temperature for lignite carbonization seems to be about 1,200° F., and at that temperature the retorting of wet lignite increases the quantity of gas but greatly reduces its quality, producing a relatively large volume of the oxides of carbon usually accompanied by a reduction of residue.

USE OF ROTARY DRIER.

The losses in the quality of the gas and in the residue are far from being compensated for by the increased yield of gas, to say nothing of the loss of fuel and labor required in maintaining the proper temperature of the retort. For this reason there is no question but that the lignite as mined should either be air dried or passed through some type of drier capable of rapid and cheap removal of the moisture. For this purpose the experiments indicated that a rotary drier of the standard type used for drying coal and a variety of other materials is highly satisfactory and economical. By means of a gentle heat, produced from lignite mine waste, the moisture content of run-of-mine lignite can readily and economically be reduced to 5 to 8 per cent.

This type of drier seems to be well adapted to this purpose. The lignite, after having been passed through the drier, is generally reduced to small lumps, which can be used to much better advantage than the large sizes in the retort or carbonizing oven. When lignite thus dried is used the gas begins to distill off quickly at a retort temperature of 1,200° F. and the time of retorting is much reduced. It is further found that the quality of the gas is greatly improved, the oxides of carbon being greatly reduced, and the residue seems to be better and larger than when undried lignite is used.

TABULATED DATA SHOWING EFFECT OF MOISTURE CONTENT ON YIELD FROM RETORTED LIGNITE.

There is, therefore, no doubt about the advisability of using reasonably dry lignite if the gas produced is to be used for lighting or other domestic purposes. The following tables show clearly the effect of moisture on the yield and quality of wet and dry lignite retorted at the same temperatures.

Results of tests of effect of temperature and moisture on quality and yield of lignite gas from lignite mine-waste slack.

Sample No.	Moisture content.[a]	Temperature.	Time.	Yield of gas per ton of fuel.	Analysis of gas.						
					Illuminants.	Carbon monoxide.	Hydrogen.	Methane.	Nitrogen.	Oxygen.	Carbon dioxide.
		°F.	*Hours.*	*Cubic feet.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Dried	300	1	50	0.0	0.0	0.0	0.0	81	19	0.0
2	.....do	300	2	76	.0	.0	.0	.0	81	19	.0
3	.....do	300	3	83	.0	.0	.0	.0	81.2	18.6	.2
4	.....do	600	1	575	.0	.1	.0	.0	81.3	18.4	.2
5	.....do	600	2	810	.0	.4	.0	.0	80.7	16.8	2.1
6	Wet	600	2	91.2	.7	4.9	4.6	3.1	58.6	10.9	17.2
7	Dried	900	1	2,807	.0	4.2	.0	.0	74.2	15.2	5.8
8	.....do	900	2	3,000	.7	7.0	11.1	6.0	59.1	11.9	14.2
9	Wet	900	2	1,828	1.6	1.6	1.26	11.14	23.8	3.2	57.4
10	Dried	1,200	1	4,114	1.4	11.1	15.9	6.6	17.1	1.1	46.8
11	.....do	1,200	2	4,268	1.3	10.9	17.0	15.9	7.6	1.2	46.1
12	.....do	1,200	3	4,275	1.5	9.9	17.8	16.9	6.8	1.2	45.9
13	.....do	1,500	1	7,396	1.2	16.7	27.5	16.4	6.7	1.1	30.4
14	.....do	1,500	2	7,502	1.4	17.3	31.9	15.0	5.0	1.1	28.3

[a] "Wet" means a moisture content of 28 per cent present in the sample.

Results of tests to indicate yield of lignite residue at various temperatures.

	Temperature of retort.	Time of run.	Yield of residue.	Calorific value per pound of coal.	Analysis.			
					Moisture.	Volatile matter.	Fixed carbon.	Ash.
	°F.	*Hours.*	*Per cent.*	*B. t. u.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lignite as charged				8208	27.00	35.20	32.60	5.20
Residue 1	1,060	1.3	52.65	11,822	.00	28.78	63.37	7.85
Residue 2	1,265	1.3	45.66	11,940	.00	12.70	77.05	10.25
Residue 3	1,200	.58	60.00	11,794	3.65	19.90	68.15	8.30
Lignite as charged				8,460	25.05	34.80	35.15	5.00
Residue 5	1,365	.84	43.50	12,240	.35	8.05	80.60	11.00
Residue 6	1,400	1.3	42.30	12,186	.00	8.40	80.50	11.10
Lignite as charged				9,940	8.55	40.55	44.25	6.65
Residue 7	1,500	1.3	50.00	12,442	.00	7.00	81.40	11.60
Residue 8	1,430	.66	53.00	12,116	.00	10.80	78.20	11.00
Residue 9	1,500	.66	53.00	12,324	.00	7.70	80.55	11.75
Residue 10	1,600	.66	52.00	12,400	.00	6.20	80.25	13.55
Lignite as charged				9,870	9.90	39.60	42.85	7.65
Residue 11	1,240	1.3	57.00	11,905	.00	14.20	75.65	10.15
Residue 12	1,380	1.0	60.00	12,512	.00	7.25	82.20	10.55

COMMENTS ON TABULATED DATA.

Regarding samples 8 and 9 it will be seen that at 900° F. nearly two hours was needed to remove the bulk of the moisture, and at that time only 1,828 cubic feet per ton of gas had been liberated as against 3,000 cubic feet of gas liberated from dry coal at the same time and temperature. It is always observed, however, that the total quantity of gas produced from the wet coal is greater when the corresponding weight of dry coal is used; but, as will be noticed, the gas produced from the wet coal contained 57.4 per cent of carbon dioxide as against 14.2 per cent from dry lignite.

Regarding samples 5 and 6, it will be noticed that at 600° little gas was driven off in two hours from the wet coal, but in the same time and at the same temperature 810 cubic feet was driven off from the dry coal. The wet coal gave 17.2 per cent of carbon dioxide as against 2.1 per cent in the dry coal.

These tests were made with lignite mine slack, and although in these series wet coal was not tested at 1,200° F., many other tests were made with wet and dry lignite at temperatures of 1,200° to 1,400° F., and the results were of a similar character, the oxides of carbon being invariably higher in gas produced from wet coal.

In general, the higher the retort temperature the larger the volume of gas, especially when the lignite is wet. As stated subsequently, 1,200° F. seems to be about the proper temperature for carbonizing lignite, and when carbonizing is done in a retort holding 400 pounds, the gas from dry lignite can nearly all be driven off at 1,200° F. in three to four hours, whereas when wet coal is used little gas is driven off in the first two hours when the temperature is at 900° F., and even at 1,200° F. five to seven hours is usually required to remove the gas.

It will thus be seen that if wet lignite is used, the time of carbonization is greatly extended, and consequently a large extra expense is incurred. At present the data as to the effect of retorting moist lignite on the ammonia and tar yields are incomplete. However, as regards the effect of temperature on the yields of gas, residue, and by-product, the experiments and tests herein reported lead the author to believe that 1,200° to 1,400° F. is the best temperature for the distillation of reasonably dry lignite.

As has already been stated, the temperature of carbonization for maximum efficiency is a matter of great importance. Of course, the lower the temperature the more economical the process becomes. There is no question but that dry lignite parts with its gases at a much lower temperature and much more rapidly than does ordinary bituminous gas coal. For the simple production of residue for briquetting purposes, if the gas were not to be saved, some means might be devised for driving off the gases economically, provided sufficient quantity were yielded with sufficient rapidity.

LOWER TEMPERATURE LIMIT OF EFFICIENT LIGNITE-GAS DISTILLATION.

For the purpose of determining the lower temperature limit of economic and efficient lignite-gas distillation, a series of tests was made, the temperature used ranging from 300° to 1,500° F., and by referring to the table on page 36 the relative yields and quality of gas obtained from the carbonization of dry lignite at 300°, 600°, 900°, and 1,500° F., may readily be seen. In this table, however, the total yield of gas shown is not as high as normal for the reason that in the tests mine waste was used instead of run-of-mine lignite, but the relative yields may be readily seen. In the tests represented by the table the gas was practically all off after the mine waste had been treated in the retort at 1,500° F. for two hours. The results given, however, should be considered along with results of tests of tar yields shown in the table on page 48, and the table on page 37, showing the results of tests to determine the lignite residues at various temperatures, and also in connection with the table on page 39, showing the results of tests to determine the lignite gas, residue, and tar yields at various temperatures. The results shown by the curves in figure 1 also should be considered here.

In all of the tests just mentioned it was not intended to procure a complete distillation of the gas, but a partial carbonization. It will be seen that although the gas yield was increased by increasing the temperature of retorting up to 1,500° F. or more, there is a corresponding loss in the tar and residue yields.

The results presented in the tables likewise show that the best temperature for the maximum tar yield appears to be about 1,200° F., with sufficient time for the complete distillation. After this temperature had been exceeded, the tar yield generally lessened, as also did the residue. Comparatively little tar was produced at a temperature less than 900° F. The results of the tests mentioned seem to be in harmony with the general results obtained with other coals by Porter and Ovitz.[a]

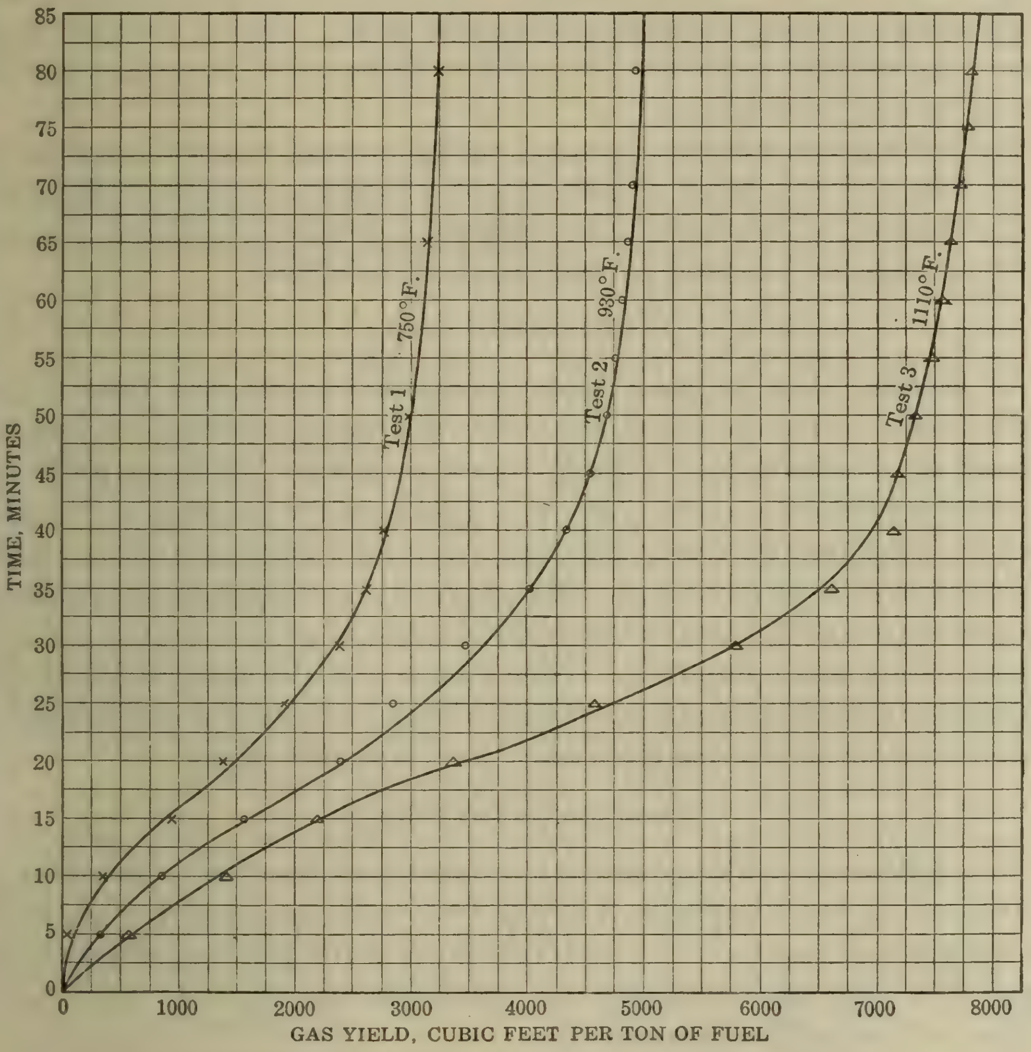

FIGURE 1.—Effect of time and temperature on lignite gas yield.

Results of retort tests of lignite[b] to determine effect of temperature and time of retort treatment on yield of tar.

Sample No.	Duration of test.	Temperature.	Yield of tar per ton of lignite.	Specific gravity of tar.
	Hours.	° *F.*	*Pounds.*	
1	1	900	39.26	0.9144
2	3	900	46.20	.9492
3	1	1,200	67.00	.9776
4	3	1,200	77.78	.9711
5	1	1,500	61.80	.9467
6	3	1,500	56.40	.9310

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[a] Porter, H. C., and Ovitz, F. K., The volatile matter of coal: Bull. 1, Bureau of Mines, 1910, 56 pp.

[b] Lignite mine-waste slack, containing about 20 per cent moisture.

RETORT TESTS OF BITUMINOUS COAL AND OF LIGNITE.

In order to obtain a more satisfactory basis for a comparison of the yields of gas and residue and the character of each in connection with the temperature of retorting bituminous coal and lignite under the same conditions, comparative runs in the small experimental plant were made with bituminous coking gas coal and with lignite containing a fairly high percentage of ash. Careful records were made in each run so that a comparison of the more important results could readily be made.

In making the tests the general methods employed with gas coals were followed to a large degree, in order that the results of the tests might furnish a standard for comparative purposes and also because both coals were adapted to the standard treatment.

PROCEDURE IN TESTS.

In making each of these tests 2 pounds of coal was used. The retort was so arranged that temperature readings could be taken by means of a standarized thermocouple connected with an accurate Siemens and Halske galvanometer. Temperature readings were made and gas-yield records were taken throughout each test until no more gas was driven off; the gas yields were then computed to standard temperature and pressure; the residue was cooled and drawn and the residue yield was computed. The residue was also analyzed and calorimeter determinations were made and an analysis and a calorimeter determination of the gas from each test were also made.

RESULTS OF THE TESTS.

The following table presents the results of the tests, including a statement of the composition of the two coals used and the analyses of the gas and residue. In each of the tests the gas was run directly from the hydraulic main to the gas holder in order to avoid any chance of loss in gas content.

Results of retort tests to determine comparative gas, residue, and coke yields from bituminous and lignite coals.

	Moisture.	Volatile matter.	Ash.	Fixed carbon.	Sulphur.	Heating value. per pound.	Gas.		Yield of residue.	Yield of coke.
							Gas yield per pound of coal.	Heating value per cubic foot.		
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*B.t.u.*	*Cu.ft.*	*B.t.u.*	*P. ct.*	*P. ct.*
Lignite	11.53	35.18	[a]17.20	36.09	1.44	8,675	5.08	415	55.12	....
Bituminous coal	5.90	30.15	7.50	56.45	1.40	12,947	5.35	480	....	66.60
Residue	.80	3.10	20.15	75.95	1.27	9,740	....	....	....	....
Coke	.00	.50	8.15	91.35	1.24	13,543	....	....	....	....

[a] An unusually high ash content.

Results of retort tests to determine comparative gas, residue, and coke yields from bituminous and lignite coals—Continued.

Kind of coal.	Yield of gaseous constituents.						
	Carbon dioxide.	Illuminants.	Oxygen.	Carbon monoxide.	Hydrogen.	Methane.	Nitrogen.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lignite	13.53	3.38	0.95	20.61	38.53	19.72	3.28
Bituminous	7.20	3.10	.90	4.55	45.55	31.60	7.10

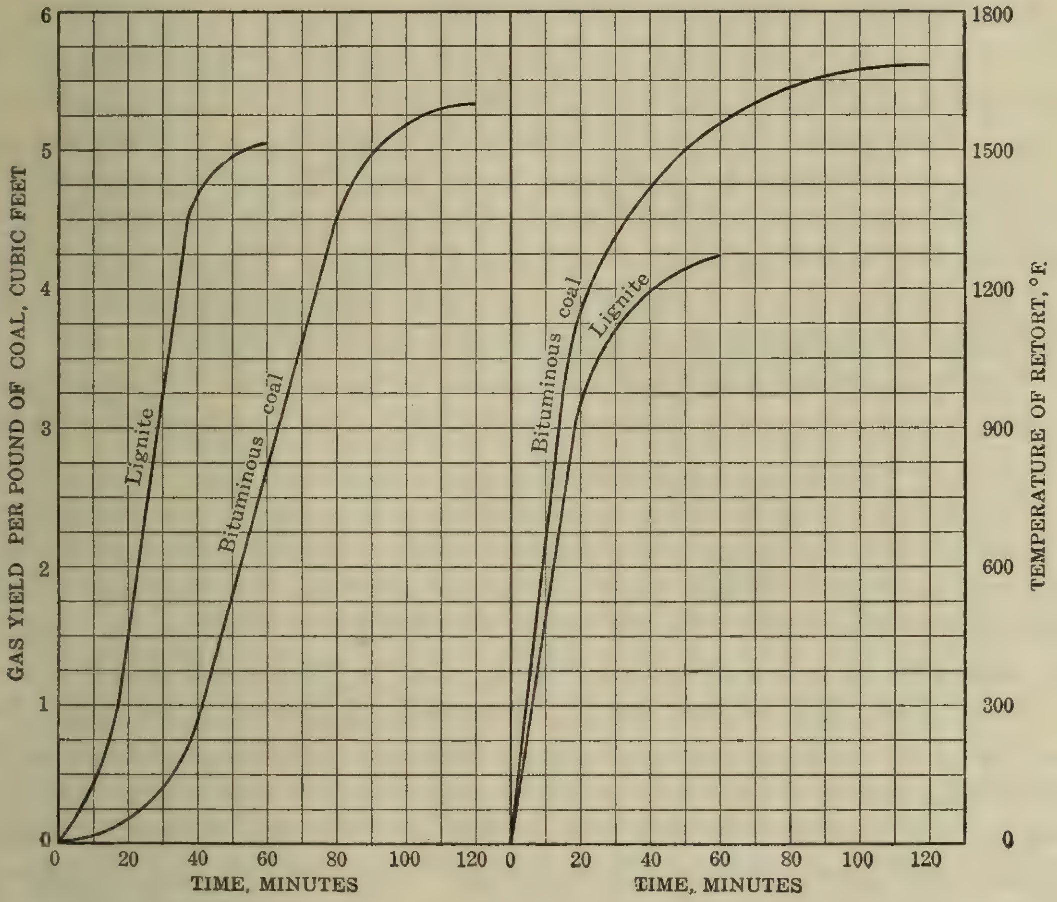

FIGURE 2.—Relative yields of gas from lignite and from bituminous coal at different temperatures and time of treatment.

The curves shown in figure 2 indicate the relative yield of gas from lignite and from bituminous coal retorted at different temperatures and at different lengths of time, the treatment being continued until the gas yield was completed.

COMMENTS ON THE RESULTS.

The curves show that the gas was removed from the lignite in about one-half the time required to remove it from the bituminous coal. The temperature required to remove the gas, it will be seen, was only 1,270° F. for lignite as against 1,665° F. for bituminous coal. The results show, in a marked manner, the ease of carbonizing lignite, and the fact that the required temperature is so much less and the necessary time of treatment only about one-half as long means, of course, a large saving in the relative cost of carbonizing, as compared with the cost of carbonizing bituminous coal.

The tests also plainly showed that the principles used in the manufacture of illuminating gas and coke may be applied successfully with proper modifications for carbonizing lignite.

The analyses of the residues showed that there was a relatively greater increase of heating value in the residue than in the coke produced from the bituminous coal, a result that would have been more marked had all of the moisture been present in the lignite and had not the sample of lignite been unusually high in ash. The yield of residue, it will also be seen, was large, much larger than might be supposed could be procured from lignite, and the coke from the bituminous coal was high in both yield and quality. The gas yield from the lignite was nearly as high as from the bituminous coal, although the time of heating and the temperature were far less.

It will also be noticed that the heating values of the crude gas were not as greatly different as were the differences in temperature and in time of production. In comparing the composition of the gases it will be readily seen that the most marked differences are found in the increased amount of carbon monoxide and carbon dioxide and in the correspondingly smaller yield of methane from the lignite. This lignite gas, however, was an excellent heating and power gas, and, as shown later, was well adapted to lighting by the use of the mantle.

Physically, the lignite residue is greatly different from the coke obtained in the carbonizing process. The coke from bituminous coal was delivered from the retort in characteristic silvery gray porous lumps, whereas the lignite was delivered from the retort in small shrunken fragments of a dull black on the outside but having a shining black surface when broken. The lignite residue is of little value in the form in which it is discharged from the retorts, but when briquetted, makes an excellent fuel, which, on account of its nonfusing quality, renders it more desirable than coke for burning in stoves and for many other purposes.

It will thus be seen that the low temperature at which dry lignite can be successfully carbonized and the rapidity with which this carbonization takes place will materially aid in reducing the cost in the use of lignite in a commercial plant.

TYPES OF CARBONIZING OVENS.

CLOSED RETORT.

Lignite could be carbonized by several methods, the choice depending on the situation of the plant and whether the gas was to be used for domestic or for power purposes, or not at all. In the discussion thus far we have considered the carbonization as having been carried on in closed retorts, such as are commonly used in city coal-gas plants. This type of ordinary horizontal retort can be used satisfactorily in the production of gas and by-products from lignite. It is the type of retort used in the experimental station and from which most of these results were obtained.

This type of retort is used extensively with bituminous gas coal for the production of coal gas for small cities, but if lignite were to be carbonized in sufficient quantity to supply the residue for a commercial briquetting plant, there would be a large volume of gas produced and a rather large number of horizontal retorts would be required. It is quite probable that in such a case a better type would be an inclined or a vertical retort, either of which can be procured in large capacities and so constructed that the cost of operation is comparatively small.

ADVANTAGES OF INCLINED AND VERTICAL RETORTS.

Lignite would seem to be especially well adapted to treatment in the inclined or in the vertical retort. Its residue does not coke or expand as does the residue from bituminous or coking coal. On the other hand, the lignite residue contracts materially and remains in separate shrunken broken fragments which can be made to discharge easily from an inclined or vertical retort.

Although the inclined or the vertical type of carbonizing plants require considerable initial outlay, the ease and low cost of their operation and the large yields of by-products and residue from them would indicate their economic adaptation to the carbonizing of lignite coal. So far as is known no trials have been made in this type of retort, but there seems to be no reason why the retorts should not be admirably adapted for the purpose. The ordinary horizontal types of by-product ovens, most of which are discharged by a mechanical pusher, would probably not be satisfactory for use with lignite for the reason that the lignite residue breaks into too small fragments to be handled mechanically by the pusher without danger of packing and sticking in the retort. Some modified form might be devised that would be satisfactory, but it is doubtful whether such a form would have any especial advantage over the vertical or inclined retorts, which are probably well suited to the treatment of lignite.

RESULTS OF USE OF BEEHIVE OVENS.

In some instances it might be desirable to briquet lignite, if the deposits were so located that there would be little or no demand for gas, at least for domestic purposes. It would then be desirable to use a carbonizing system that could be installed and operated cheaply. The beehive oven, which is extensively used for the production of coke from bituminous coal when the recovery of gas is not wanted, could doubtless be used in the carbonizing of the lignite but not with economy or satisfaction. For this reason small carbonizing ovens of modified type have been used by the writer and with lignite have given much better results than could be obtained in the beehive oven. The ovens were 6 feet wide and about 8 feet high and were supplied with air pressure and gas exhauster.

The lignite as charged into these ovens had the same moisture content as when mined, although dry or partly dry lignite would have doubtless given better results. The hot ovens first drove off the moisture and then the gas. The excessive moisture temporarily reduced the temperature of the ovens, but as soon as the moisture had been driven off the necessary oven temperature was restored. The rate of carbonization and the yields were so promising that larger modified ovens of this type will be installed, so constructed as to permit the saving of a part of the gas. It is expected that from the larger modified ovens still better results will be obtained, together with the recovery of sufficient gas to be of value for the burning of clay products, or for use in an internal-combustion engine. This special type may present possibilities for localities where there is comparatively little use for domestic gas, a condition frequently encountered near lignite deposits. For use in these ovens, as in retorts, partly air-dried lignite should be employed.

DATA OBTAINED FROM USE OF SMALL MODIFIED OVENS.

No data have yet been procured from the use of the larger modified ovens of this type. However, some information has been obtained as to the quantity and quality of residue and gas produced in a small experimental modified oven and the tables following show the results obtained.

Results of tests to determine the lignite residue resulting from operation of small modified oven.

Sample.	Yield of residue.	Analysis of residue.				
		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Calorific value of residue per pound.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*B. t. u.*
A	53.3	0.00	20.40	69.53	10.07	12,590
B	49.4	.00	19.98	70.20	9.82	12,300
C	43.3	.00	10.42	80.90	8.68	13,200
D	43.3	.00	15.85	74.30	9.85	12,905
Average	47.3	.00	16.66	73.73	9.61	12,749

Analyses of gas (unpurified) from a small modified oven.

Sample No.	Illuminants.	Carbon monoxide.	Hydrogen.	Methane.	Nitrogen.	Oxygen.	Carbon dioxide.	Calculated heating value per cubic foot.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*B. t. u.*
1	0.6	6.8	3.05	11.4	50.95	3.4	23.8	166
2	.3	5.3	1.50	12.4	54.20	4.6	21.7	162
3	.7	5.6	16.10	12.8	35.10	1.0	28.7	222
4	.6	7.7	11.60	14.0	49.10	2.0	15.0	224
5	.8	7.6	13.40	16.8	18.00	1.2	42.2	263
6	.3	4.4	3.34	9.6	61.46	3.5	17.4	135
7	.6	4.0	4.65	5.55	69.00	2.8	13.4	100
Average	.56	5.90	7.66	11.79	48.26	2.63	23.20	182

The results of tests indicate that it is possible to obtain from ovens of the type used in the tests a yield of about 50 per cent lignite residue, having about 70 per cent fixed carbon and a calorific value of about 12,000 British thermal units and in addition recover by-product oven gas having a calorific value of probably at least 150 British thermal units per cubic foot.

In the recovery of this oven gas the first part is not removed, but is allowed to burn in the oven in order to bring up the temperature. In a like manner the recovery of the gas is discontinued a short time before the evolution of the gas ceases. Thus the oven temperatures are retained and a considerable recovery of gas is expected to be made in the large ovens.

VALUE AND USES OF LIGNITE GAS.

CHARACTER OF LIGNITE GAS.

From the yields of lignite gas in the tests reported in this bulletin, which represent the character of gas produced on a considerable scale and probably aggregating 1,000,000 to 2,000,000 cubic feet, it is evident that from the carbonization of lignite there can be recovered unpurified gas that will have a heating value of nearly 400 British thermal units per cubic foot, and of sufficiently good quality to render it valuable for many purposes. Furthermore, the yield of gas from partly air-dried lignite is excellent, reaching 10,000 or 11,000 cubic feet per ton. This quantity would, of course, be reduced if calculated on the basis of wet lignite.

The retorting has been done at comparatively low temperatures, thereby reducing considerably the cost of production. The gas is rather high in carbon dioxide and hydrogen, as will be seen by the analyses, but, as has already been stated, the high content of those constituents is undoubtedly due in a large degree to the moisture and air that are absorbed on account of the porous character of the lignite. Part of the moisture, however, is derived from the air in the retort and pipes, a condition unavoidable in stopping and starting an experimental plant, but such moisture would be much less proportionally if the gas were manufactured continuously in a large plant. In retorting, the oxygen from the air, present from the sources just mentioned, combines naturally with the carbon forming a larger proportion of carbon dioxide and carbon monoxide, thus leaving a relatively large proportion of nitrogen.

The gas made from lignite has been subjected not only to a large number of chemical and calorific tests, but has also been put to a great variety of practical uses. It has been burned in the ordinary manner for lighting purposes and gives a most satisfactory and brilliant light when used with the ordinary mantle burner, although it has small illuminating qualities when used in the open-tip burner. When used with a mantle it produces a clear smokeless flame that, with proper adjustments, may be easily regulated so that the light will equal that produced from the use of ordinary city gas with mantles.

A series of photometric tests of the gas used with a mantle have been made, and show excellent results. The gas seems sufficiently free from sulphur and other objectionable impurities to permit its use without complete purification. The cost of the gas supplied for domestic purposes would thus be materially reduced. Of course the gas would be subjected to the usual water scrubbing.

It is true that the gas is rather high in carbon-dioxide content, but if the gas were produced as a by-product in the manufacture of briquets from lignite, it could be made at such a low cost that if distributed unpurified it could be sold at a correspondingly low price and used with mantles for lighting and for cooking without the necessity of treatment for the removal of carbon dioxide. The gas could be purified in the usual manner and enriched, but the wiser way would seem to be to sell the gas at low enough price so that purification would not be necessary.

The author has used the gas without purification rather extensively for lighting, heating, and experimental purposes. Purification, however, could be done by the methods usually employed for purifying ordinary coal gas, and if the gas were thus purified, the composition and heating power would be considerably modified. The heating value developed would probably be increased to 450 British thermal units. The gas could then be further enriched if desired.

The lignite gas is naturally what is known as a "dry" gas and when delivered from the holder is almost free from tar and other matter that in ordinary city gas often causes trouble through condensation and clogging. Its freedom from such constituents would be a material aid in the practical distribution and use of lignite gas, especially in cold climates. The most severe and continued tests have been given lignite gas to determine the condensation produced when it is carried in slightly protected pipes during cold weather. In the tests no trouble was experienced from condensation.

The gas has been successfully used not only for lighting, cooking, heating, etc., but also in a small way for generating power. It has given uniformly excellent satisfaction, with unexpectedly high efficiency.

USE OF LIGNITE GAS FOR POWER PRODUCTION.

The use of lignite gas either from retort ovens or modified ovens presents many commercially attractive features. Although the power tests have not as yet been carried very far, enough has been done to prove that the gas can be used with entire satisfaction for power in gas engines. Several tests have been run with modified gasoline or gas engines at the mining substation and at the school of mines. At the latter the tests were made in comparison with standard city gas, and the lignite gas was found especially satisfactory, developing relatively high efficiency.

There is little doubt that lignite gas can be successfully employed for power purposes, and that power can be produced at such a low figure as to exert a marked influence in the development in the Western lignite area of a variety of industries dependent on cheap and abundant power, which, with the establishing of large by-product plants, may become a close rival of hydroelectric power.

Because of the ease with which the gas is produced, the low cost of the original lignite, and the value of the residue when briquetted, the gas should have a large commercial value for lighting, heating, and power purposes in many districts, especially in view of the low price for which it could be sold if manufactured as a by-product in a plant used also to produce briquets from lignite residue.

YIELD OF AMMONIA AND TAR FROM LIGNITE DISTILLATION.

Tests to determine the yield of ammonia from lignite indicated a yield as large as could be expected. This by-product in the form of ammonium sulphate is of considerable commercial value and is used in many ways, especially as a fertilizer. The author has not done a large amount of work on this problem, but sufficient determinations have been made to show an average yield of approximately 17.4 pounds of ammonium sulphate per ton of dried coal, or about 25 pounds per ton of briquets. The by-product is thus of sufficient value to be worthy of careful consideration because if saved in a large plant it would return considerable revenue and reduce the final cost of briquetting.

By reference to the table showing tar yields at different temperatures (p. 39) it will be seen that at temperatures of 900° to 1,500° F. approximately 50 pounds of tar can be recovered on an average from the carbonization of 1 ton of partly air-dried lignite. The exact quantity will fluctuate with the character of the lignite, the temperature of distillation, and the percentage of moisture present in the lignite. The maximum yield seems to be obtained at approximately 1,200° F. At a higher temperature it is quite evident that destructive distillation of the tar begins, thereby reducing the tar yield. The destructive distillation also causes an increased gas yield at higher temperatures, seemingly due to the breaking up of the hydrocarbons of the tar.

The table following gives the percentage of tar in the lignite used in nine tests:

Tar yields in retort tests of lignites.[a]

Sample No.	Quantity of tar per ton of lignite as charged.	Proportion of tar in lignite.	Sample No.	Quantity of tar per ton of lignite as charged.	Proportion of tar in lignite.
	Pounds.	*Per cent.*		*Pounds.*	*Per cent.*
1	26.00	1.30	7	39.26	1.96
2	27.00	1.35	8	46.20	2.31
3	77.78	3.89	9	55.00	2.75
4	56.40	2.82			
5	61.80	3.09	Average	50.72	2.54
6	67.00	3.35			

[a] The lignite was partly dried, containing 8 to 27 per cent moisture.

Variations in temperature affect the character of the tar, its specific gravity ranging from approximately 0.92 to 0.97. Under ordinary conditions the tar is a thin fluid of a peculiar odor and an oily character. The tar seems to be high in paraffin ingredients and in lignite oils, and seems to be especially well adapted for use as a wood filler, many large and small scale tests having been made of such use of the tar without further treatment. For this and other purposes it should be of considerable commercial value.

DERIVATION OF OIL FROM LIGNITE TAR.

Lignite tar is not in its natural condition adapted to briquetting purposes, but by special methods of treatment that are being developed by the writer it seems entirely probable that a large proportion of lignite tar may be used in connection with other material as an ingredient of the binder for briquetting the lignite residue, thus reducing considerably the cost of the briquet binder.

As has already been stated, the tar recovered from lignite carbonization, under proper conditions, shows an oily and paraffin character and remains under normal temperature in a free fluid condition.

Work has been begun under the direction of the writer for the recovery of several by-products from this lignite tar, and it has been found that an appreciable yield of heavy oil may be derived from the proper treatment of lignite tar that has been recovered at the proper carbonizing temperature.

As a by-product in the manufacture of lignite-residue briquets, it would appear from the work thus far done that the oil would amount to about 2 gallons for each ton of briquets produced. The flash point of the oil seems to vary between 120° and 185° F., the exact temperature depending on the conditions of carbonization and distillation. The oil undoubtedly aids in keeping the heavier and thicker pitch-forming hydrocarbons in solution in raw lignite tar.

The oil should have considerable commercial value. It could probably be used to advantage in internal-combustion engines adapted to the use of heavy oils, especially as the oil does not appear to deposit any troublesome tarry matter. A similar use of lignite oil is suggested by Allen.[a]

It will thus be seen that the lignite tar can undoubtedly be made of considerable commercial value in a large by-product plant by utilizing it in any of the various ways suggested.

LIGNITE-BRIQUETTING EXPERIMENTS.

As already mentioned, the process developed under supervision of the author for the successful manufacture of briquets from lignite is intimately associated with the production of gas; and according to this system a complete briquetting plant would also include a simple gas plant or at least the carbonizing part. Consequently, the discussion of the manufacture of gas from lignite has preceded a consideration of the subject of briquetting.

DETAILS OF PROCESS SHOWN TO BE ESSENTIAL.

The process of lignite briquetting that has been evolved at the school of mines of the University of North Dakota and at the mining substation depends on the concentration of the raw lignite into a fuel of relatively high heating value, and of sufficient value to be shipped for some distance for domestic and other use.

Such concentration depends on, first, the removal of the moisture, second, the expulsion and saving of the volatile gas, and third, the binding together of the concentrated residue into strong and durable briquets of suitable size. As the coal is removed from the mine it contains a high proportion of moisture, usually more than 30 per cent; that is, about one-third of every ton of raw lignite as mined is water. The moisture content is largely responsible for the difficulty in the successful introduction of lignite except in the immediate vicinity of the mines.

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[a] Allen, I. C., Heavy oil and fuel for internal-combustion engines: Technical Paper 37, Bureau of Mines, 1913, 36 pp.

The cost of shipping for long distances fuel containing so much water is excessive. In addition, the heating value of the coal is reduced by the high proportion of water present. On standing, a part of the water evaporates from the coal, but the evaporation tends to reduce the lumps to slack, causing thereby a large amount of waste. In converting the raw lignite into the condensed briquets, the first step is the removal of the water in a manner least harmful to the lignite.

METHOD OF DRYING THE LIGNITE.

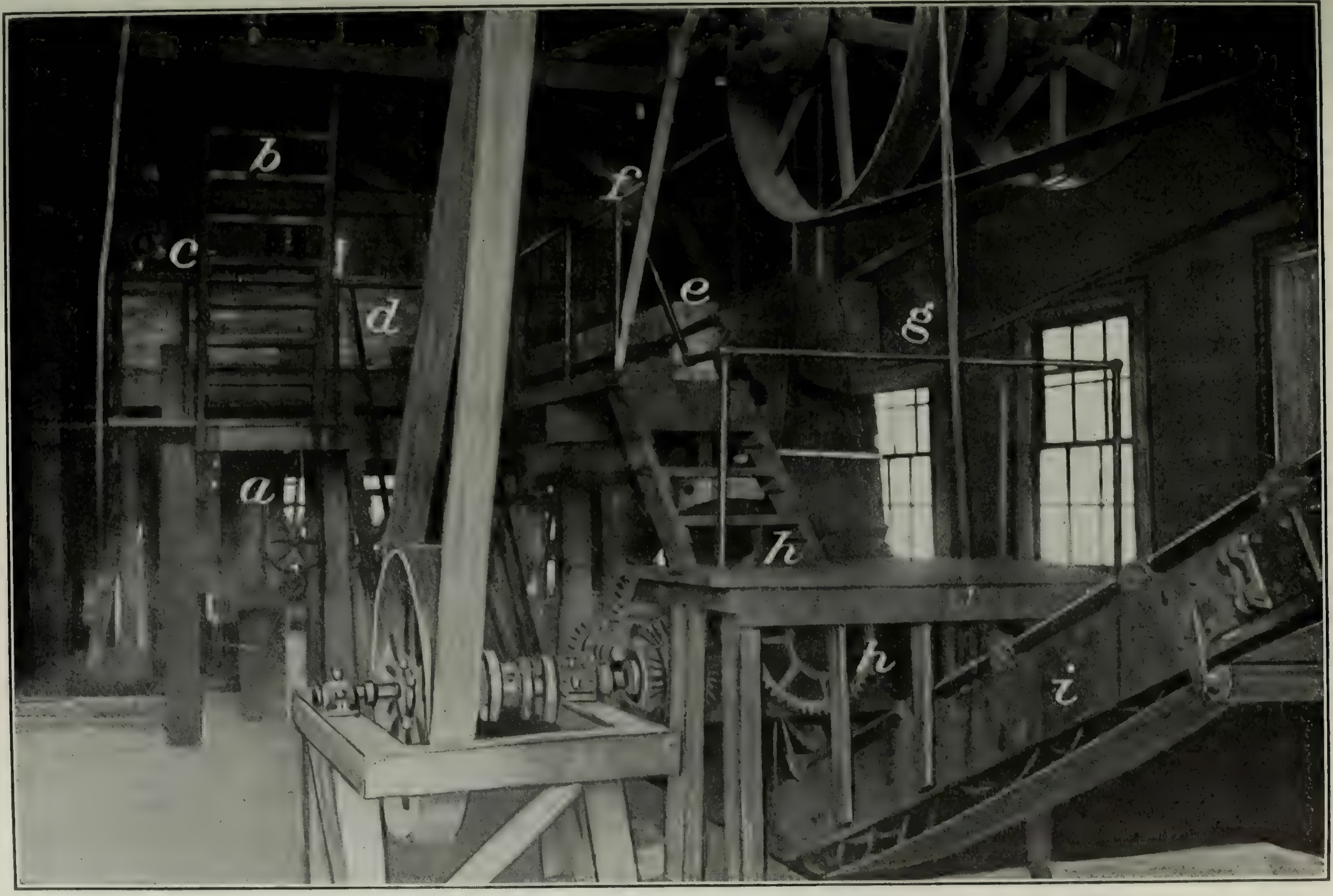
In the experimental plant, if the gas is to be saved especially for domestic lighting or heating, the drying of the lignite is done first by means of a rotary drier. The large lumps as removed from the mine are crushed to about the size of an egg. They are then run through the drier, which removes 75 to 90 per cent of the moisture. There are a variety of types of driers that can be used for this purpose, but the style employed at the experimental plant consists of a sheet-steel cylinder attached to a revolving shaft which serves to feed and mix the coal while the cylinder is slowly revolving.

Beneath the cylinder is a small fire box so arranged that it will gently heat the revolving cylinder. The whole machinery is inclosed in brickwork. Slack coal is used for firing, and only a small amount is required per ton of raw coal dried. The power per ton for driving the drier is also small, and the operation is efficient.

After the coal has been sufficiently dried it is conveyed to the gas-retorting room and is treated in the retort after the manner already explained. This process is usually completed in about four hours. At the end of this time the retort is discharged and the remaining coal residue conveyed to a brick bin, where it is quenched with a spray of water.

BRIQUETTING PLANT OF NORTH DAKOTA SCHOOL OF MINES.

The experimental briquetting plant (Pl. III) is continuous, with a capacity of 15 to 20 tons per 10 hours. In this plant the carbonized residue goes first to a disintegrator, which breaks all lumps of residue to a ¼-inch size and finer. The broken residue is then conveyed to a set of rolls which reduce it to the proper size for briquetting. It is then lifted by elevator (*a*, Pl. III) to a bin (*b*, Pl. III), from which it passes through an automatic feeder (*c*, Pl. III) which gives the correct proportion of residue to binding material.



PART OF LIGNITE-BRIQUETTING PLANT AT SUBSTATION AT HEBRON, N. DAK.

a, Elevator; *b*, ground-residue bin; *c*, measuring and feeding machine; *d*, preheater and conveyor; *e*, mixer for binders and lignite; *f*, binder tanks; *g*, cooler to temper mixture; *h*, *h*, briquetting press; *i*, briquet conveyor, leading to storage bins.

At this point an automatic feeder delivers also the proper amount of ground screenings, or low-grade flour, 1 to 2 per cent generally being used. The mixture is then delivered to a preheater and conveyor (*d*, Pl. III) which conveys and mixes the dry material and at the same time brings it to a temperature of about 100° F.; thence it is delivered into the mixer (*e*, Pl. III). At this point the binding pitch is introduced through a rotary meter, by means of which the exact amount of pitch binder desired may be used. Most of the pitch used has a melting point of 145° F.

The pitch is melted in a steam-heated tank (*f*, Pl. III), from which it flows by gravity to the meter. It is then sprayed and blended with steam in the mixer. The mixer is steam-jacketed and so designed that it thoroughly mixes the binding material and the lignite residue, at the same time moving the mixture forward and delivering it at exactly the proper speed for the briquetting press. On its way to the briquetting press the mixture is carefully cooled to the proper temperature by a special device (*g*, Pl. III) which can be regulated to meet the changes in atmospheric temperature. The mixture then passes through the press (*h*, Pl. III) and the briquets are delivered to a cooling belt (*i*, Pl. III) which conveys them to storage bins.

The plant is complete and no hand work is done from the time the residue is delivered to the crusher. All of the machinery is carefully timed so that every part operates at the proper speed and delivers exactly the right proportion of material. Considerable skill is required in the operation of the plant to keep the adjustment exactly right, but the plant has been so carefully constructed that it operates uniformly and with comparatively little attention.

There are numerous details of mixing, cooling, etc., that can be properly understood and controlled only by experience. Conditions vary greatly with the kind and character of the binding material used.

BRIQUETTING PRESS USED.

The press that is used at the experimental plant is of the rotary type. It was built to order and is capable of producing 2 tons of briquets per hour. Careful consideration indicated that for the lignite material in the form being used the simplest type of rotary press would probably be the most satisfactory; moreover the simplest and most easily operated machine and the one requiring the least power seemed most desirable. The type of press shown in Plate IV, *A*, has proved satisfactory.

There are several varieties of briquetting machines. They are in the main, however, of two kinds, namely, the rotary and the plunger types. The plunger machines are made in either low or high pressure styles, and have been rather extensively used in

Europe. With certain varieties of coal and certain types of binders such presses have been satisfactory, but the rotary machine seemed well adapted to the purposes of the experimental plant and was selected for the work on the lignite.

The machine used is extremely simple in its design and operation. The material to be briquetted is fed between two rolls, the surfaces of which are covered with pillow-shaped pockets, half of a pocket being on the front roll and half on the rear roll. The rolls are so geared that the two halves of each pocket exactly match as the rolls revolve. The lignite mixture is caught between the rolls, pressed into the pockets, and formed into firm dense briquets, which, as the rolls revolve, are discharged to a belt conveyor, by which they are carried to the storage bins. The experimental press produces a briquet weighing 2¼ ounces, and when producing 2 tons of briquets per hour requires about 8 horsepower.

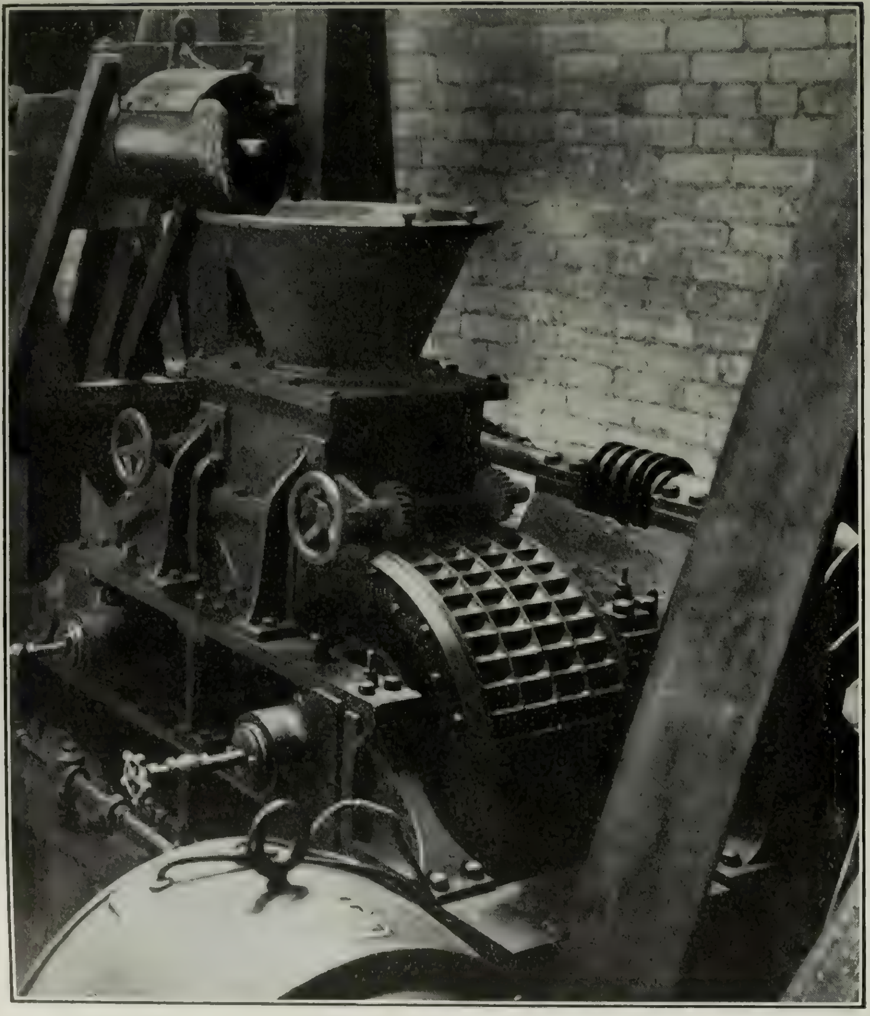
Some presses of this type have a capacity of 10 to 20 tons per hour of finished briquets, but the operation is in every way identical.

CHARACTER OF BRIQUETS MADE BY DIFFERENT PROCESSES.

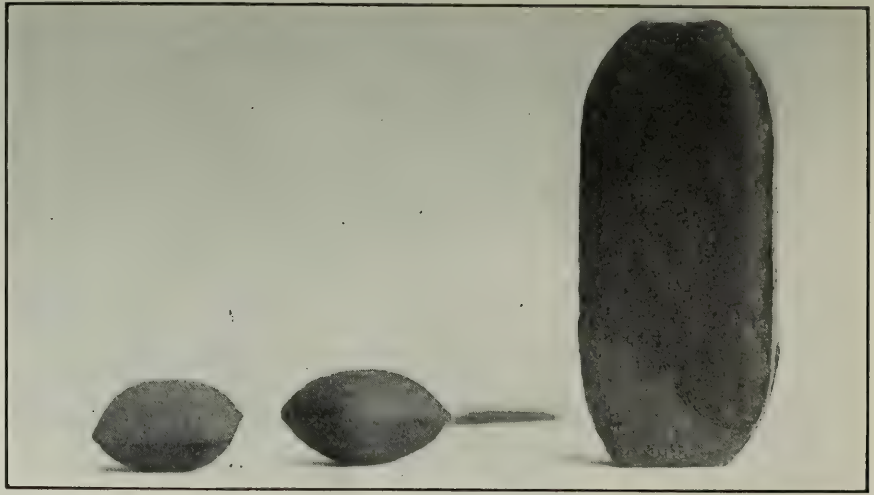
Briquetted fuels have been extensively used in Germany and in other parts of Europe, where a variety of methods of manufacturing have been employed, with varying degrees of success. With certain European coals briquet blocks have been produced without a binder, whereas with other coals lime, sugar wastes, starch, pitch, and other binding materials have been employed. Numerous attempts have been made in this country to briquet lignite without a binder merely by excessive pressure, but the plan has proved unsatisfactory. By such a process the expense for power and operation nearly equals the cost of the binder. Moreover, no satisfactory briquets of American lignites have been produced on a commercial scale without a binder. It has therefore been generally conceded that in America the best briquets are produced by the use of some binding material.

It is true that in some instances good-looking raw-lignite briquets have been obtained in a small way by the use of high pressure and without a binder. However, such briquets have not really been satisfactory. Some have appeared all right until they were exposed to the weather or to furnace heat, when they would disintegrate. Briquets are not made for looks but for fuel purposes. They must, therefore, be capable of successfully withstanding rough handling, severe weathering, and hard furnace use.

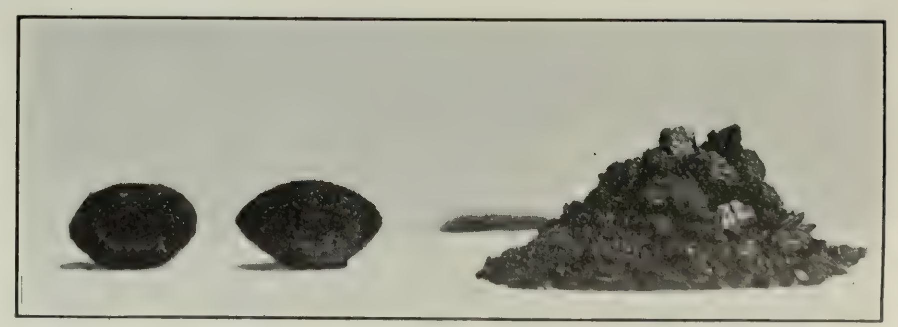
Most raw-lignite briquets—that is, those made simply from partly air-dried lignite either with or without a binder—look satisfactory when they have not been subjected to the severe tests required for



A. BRIQUETTING PRESS, SPECIALLY ARRANGED FOR EXPERIMENTAL WORK OF SCHOOL OF MINES, UNIVERSITY OF NORTH DAKOTA.



B. BRIQUETS BEFORE HEATING. AT LEFT, STANDARD LIGNITE-RESIDUE BRIQUETS; AT RIGHT, RAW-LIGNITE BRIQUET.



C. BRIQUETS SHOWN IN *B*, AFTER HEATING. LIGNITE-RESIDUE BRIQUETS IN GOOD CONDITION; RAW-LIGNITE BRIQUET EXPANDED AND DISINTEGRATED.

a commercial fuel. Some of these briquets will stand fairly well a short period of weathering, but most of them, especially those that have been made from air-dried lignite under heavy pressure and without a binder, become brittle and are easily broken even by moderate handling after having been exposed for a short time to atmospheric conditions and furnace heat.

Briquets produced from air-dried lignite from which only the water has been removed will not stand successfully ordinary furnace conditions, particularly if the briquets are made without a binder. The briquets made of the dry lignite contain all of the light volatile gases of the original lignite lumps. When briquets of this character are heated in a furnace until they begin to glow, the large quantity of light gas contained in the partly dried lignite is rapidly forced out of the briquet, causing it to either crumble in the furnace or become so fragile that a mere touch of the poker will make it fall to pieces. The dry lignite particles that have not had an opportunity to burn then begin to fall through the grate, and much material drops unburned into the ash pit. In fact, such briquets are not commercially as practical as lump lignite and, moreover, there has been considerable cost added to them in the process of drying, crushing, and briquetting.

It is true that such dry lignite briquets may on test show a calorific value as high as 9,000 or 10,000 British thermal units, but when actually burned in the furnaces this calorific value is nowhere near realized because of the disintegration mentioned. Consequently the briquetting of air-dried lignite whether without or with a binder does not promise a satisfactory commercial product.

Many efforts have been made to obtain a form of air-dried briquet that would meet the requirements of a commercial fuel, but none has suceeded in a commercial way so far as the use of Western lignites is concerned. In the briquetting of German lignites, the conditions are entirely different from those encountered in connection with most Western lignites. After much investigation and many hundreds of tests, the writer has been convinced that the most satisfactory, if not the only successful, method of briquetting lignite, is to carbonize the raw lignite so as to remove at least a large proportion of the volatile gases as well as the moisture.

The residue, as shown previously, has a greatly increased heat value, and, relieved of its excess of light gases, becomes an excellent material for briquetting. Briquets from this residue when produced as described above stand handling, weathering, and severe furnace tests with a high degree of satisfaction.

BURNING TESTS OF BRIQUETS MADE IN EXPERIMENTAL PLANT.

Plate IV, *B*, shows a large briquet made of dried lignite and two small briquets made from lignite residue by the process previously described. These two briquets were placed side by side on a fire-clay slab and introduced into a muffle furnace which was heated to redness. In a few moments the briquets were heated to the point of ignition. The small briquets burned with little flame and retained their form perfectly. The large briquet soon began to crumble, and, although unburned, soon disintegrated so far as to leave only the mass of lignite particles shown in Plate IV, *C*.

TYPES OF BINDERS USED.

Many different binders have been employed both in Government and in private tests but the one most widely used and most generally satisfactory is some form of pitch, usually what is called a rather hard pitch. Best results at the experimental plant have been procured with a pitch having a melting point of about 145° F. There are many advantages in such a binder. It is readily obtained in large quantities from coal-gas plants and from by-product coke ovens. It is reasonably cheap and is free from ash, has excellent heating qualities, and as a binder produces a strong and waterproof product. For these reasons in most of the briquetting work herein reported some form or combination of pitch binders has been used, but many other binders, such as flour, starch, gypsum, and various combination binders, have also been used. Up to the present time the best results have been achieved, however, by using a small amount of pitch as a binder base and mixing with it a small percentage of some of the other materials mentioned. Several hundred tests have been run with different binders in different proportions and under varying conditions. Probably the best and cheapest lignite-residue briquets have been made with a mixture of 5 or 6 per cent pitch blended with about 5 per cent bituminous coal dust and 1 to 2 per cent of flour or fine ground screenings from grain.

In the process of gas manufacture the author has found that about 50 pounds of tar is obtained from carbonizing 1 ton of dry lignite, or, in other words, there would be produced by the experimental methods of manufacture over 50 pounds of tar for every ton of lignite briquets produced, the exact quantity depending upon the degree of carbonization. By a simple process on which the writer is now working, the tar can probably be utilized for a considerable part of the binder material, so that probably not more than 4 per cent of pitch in addition to that derived from the lignite will be required. Or, if the lignite tar is more valuable than ordinary pitch, as now seems probable on account of its peculiar composition, it may be sold at sufficiently high price to go a considerable way in reducing the cost of the other binders required in briquetting.

Attention has already been called to the desirability of using the gas in connection with the briquetting, and to the revenue that may be derived for the plant by a combination of gas and briquetting plants, but in addition, as has already been mentioned, there is a considerable quantity of ammonium sulphate formed (about 25 pounds per ton of briquets), and this by-product has a ready market. Thus, if the various by-products are saved and the revenue derived from them is applied to the manufacture of the briquets, the cost may be materially reduced. In a large commercial plant the saving of a few cents per ton will be sufficient to net a good profit.

The briquets now being produced regularly and in considerable quantities at the mining substation are first-class in every respect. They are strong, hard, durable, and will stand weathering excellently and burn with entire satisfaction in almost any type of stove or furnace. They have been tested in a great variety of ways and have given good results.

ABRASION AND CRUSHING TESTS OF BRIQUETS.

In order to determine how well lignite briquets would stand such necessary handling as loading, shipping, and shoveling, a large number of comparative tests were made with the briquets and with the best grade of lump soft coal. Abrasive, drop, and crushing tests were included. The abrasive tests were made in a machine having two rotating cylinders on the same shaft. In one cylinder was placed a weighed quantity of lignite briquets and in the other a weighed quantity of standard coal of the same size; the cylinders were then rotated for the same period and at the same speed. At the end of the test the remaining lumps were removed, and the fine as well as the broken parts of each less than one-half inch in size were weighed and the percentage of abraded material calculated. The table following gives the results of the tests.

Results of comparative abrasion and crushing tests of various kinds of coal and of lignite briquets.[a]

Sample No.	Kind of coal.	Proportion larger than 1-inch size remaining after abrasive tests.	Crushing strength per square inch.
		Per cent.	*Pounds.*
1	Anthracite	98.50	3,950
2	Kentucky lump	93.43	1,970
3	Youghiogheny	81.20	3,680
4	do	86.65	1,510
5	Pocahontas	75.75	1,556
6	Lignite briquets	99.60	1,810
7	do	97.75	1,370
8	do	99.38	1,530
9	do	99.23	1,825

[a] Results represent averages of three tests.

The table indicates that lignite briquets withstood abrasion better than any of the coals tested, including both anthracite and bituminous varieties. The briquets would therefore stand handling remarkably well and the loss in dust would not be large.

In the crushing tests it was not supposed that the briquets would give nearly as high results as would standard coal. It will be seen, however, that the briquets were stronger than the Pocahontas coal and averaged nearly as strong as Youghiogheny coal. The results of both the crushing and the abrasion tests were remarkably satisfactory.

DROP TESTS.

Drop tests were also made in a specially designed drop-test box from which a definite weight of briquets and standard coal were alternately dropped from the same height. The percentage of broken lumps from each test was determined. Comparative breaking tests were also made by briskly striking together the briquet and the coal used for comparison. In nearly all the tests soft-coal lumps were readily broken without injury to the briquets. The breaking and drop tests indicated that lignite briquets are stronger than many bituminous coals.

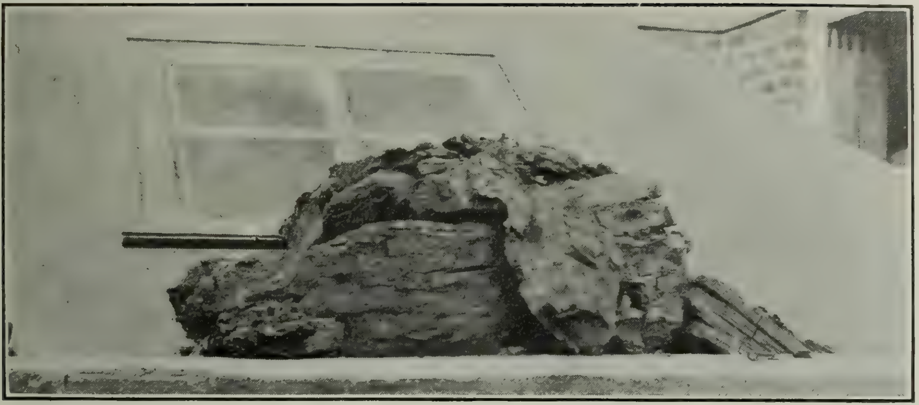
It will thus be seen, from the results of the series of tests outlined, that the briquets produced from lignite residue have excellent physical qualities and will unquestionably stand shipment and handling satisfactorily. The briquets can be considered a reasonably clean and satisfactory fuel to handle.

WEATHERING TESTS.

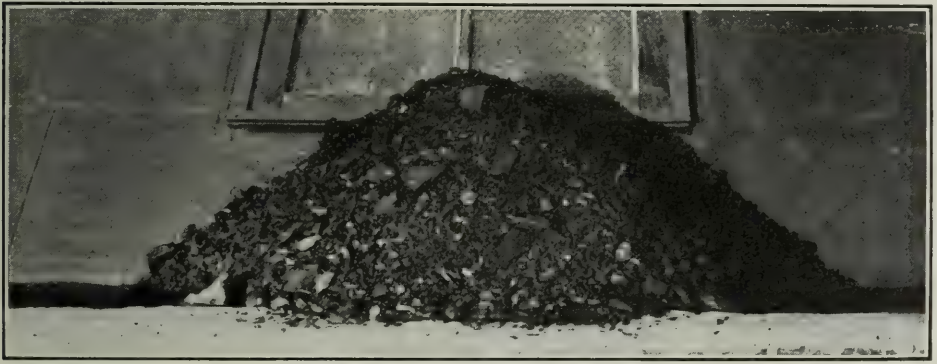
In order to determine the ability of the lignite-residue briquets to withstand weathering, a number of severe tests were made. In one set of tests a pile of the briquets was exposed on the roof of a building for one year. There the briquets were compelled to withstand all the changing climatic conditions, such as wind, heat, rain, and frost. At the end of one year the briquets were still in fairly good condition and could be used for fuel purposes. They showed only slight surface effects.

In another test half a carload lying on the ground was exposed to the weather for six months, with hardly any perceptible weathering effect. Such results show the remarkable difference in the action of weather on briquets and on the raw lignite. Lignite as mined quickly slacks into small pieces or dust on exposure to the atmosphere.

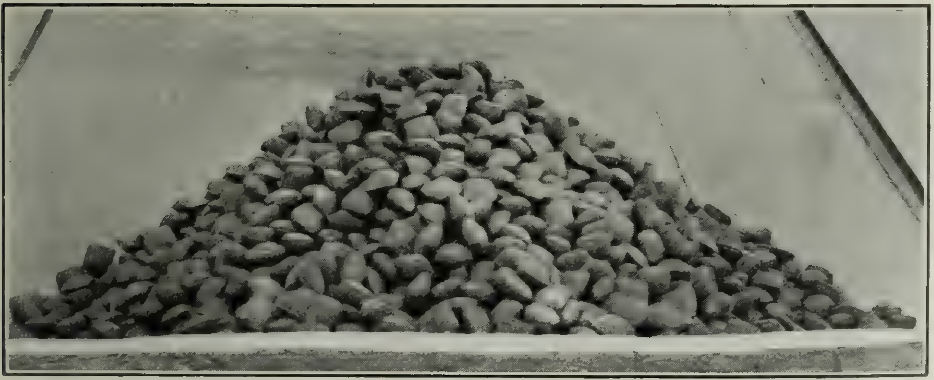
Plate V, *A*, shows a lump of freshly exposed lignite and Plate V, *B*, shows the slack produced after similar lumps had been allowed to stand a short time in the air. Plate V, *C*, shows a pile of briquets that had been exposed to the weather for six months without appre-



A. LIGNITE LUMP, AS MARKETED.



B. STACK OF LIGNITE LUMPS AFTER EXPOSURE TO WEATHER.



C. STANDARD LIGNITE-RESIDUE BRIQUETS AFTER EXPOSURE TO WEATHER FOR SIX MONTHS.

ciable effect. It will thus be seen that briquets made from carbonized lignite residue are well qualified to stand considerable exposure without material deterioration, and that the value of the process is sufficient to warrant a considerable briquetting expense on this account, to say nothing of the increased heating and other values.

The briquets stand in the furnace during the complete process of combustion without crumbling, and, as already mentioned, this quality is important and seemingly can not be obtained by any process of briquetting the simple dry lignite. Briquets made from carbonized lignite residue, however, stand through the whole period of burning remarkably well. They are frequently seen in perfect form until all of the fixed carbon has been burned. If, then, the ash is touched with a rod, it falls to a powder, showing practically no unconsumed carbon.

This property of the briquets of withstanding the effect of intense furnace heat without disintegration is one of great practical commercial value, and the fact that the ash burns clear of carbon permits a marked saving over the ash loss of bituminous and anthracite coal as ordinarily burned, for in the ash of these coals it is well known that there is a considerable proportion of unconsumed fixed carbon. Consequently, it is possible for carbonized lignite briquets, even of a lower calorific value than anthracite or soft coal, to equal or surpass such coals in actual heating results.

RÉSUMÉ OF ADVANTAGES OF BRIQUETTING.

The chief advantages to be gained in briquetting carbonized lignite as outlined are the large gain in heat value, the prevention of slacking so characteristic of this coal, the holding together of the mass during combustion, the prevention of matting in the fire box, free burning, uniformity in size, cleanliness in handling, and decrease in the losses. In addition, briquets can be used to better advantage in a variety of stoves and may be kept under more perfect control than the ordinary form of lignite. But the greatest advantages are the increased heating power and the fact that the lignite is put into a form which will stand weathering, handling, and burning without disintegration.

The briquets have many advantages over ordinary coal on account of their uniformity of size and shape, which make them well adapted to ordinary use, as they are free from the extra small and extra large fragments so often found in lump coal. There is comparatively little loss through the grate bars; they burn to an ash, in which practically all of the fuel has been consumed. Anthracite coal leaves a considerable amount of clinkers containing more or less black imperfectly burned fuel or carbonaceous matter. The complete combustion of lignite briquets is greatly in their favor as regards economy.

CALORIFIC DETERMINATIONS.

It will be seen that briquetting the lignite raised its heating power about 70 per cent and gave a calorimeter value of approximately eleven-thirteenths to twelve-thirteenths the heating value of anthracite coal. If lignite low in ash is thoroughly carbonized and the resulting residue briquetted, the briquets will show by chemical analyses an approximate composition not greatly below anthracite coal. Chemical analyses of such briquets as compared with those of raw lignite and anthracite coal are shown by the following table:

Chemical analyses and calorific values of anthracite coal, lignite, and lignite briquets.

	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Heating value.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*B. t. u.*
Lignite as mined	35.01	25.11	34.67	5.21	7,000 to 7,800
Lignite briquets	0 to 6	2 to 8	72 to 82	10 to 16	11,500 to 12,000
Anthracite	1 to 5	2 to 6	78 to 92	10 to 15	12,000 to 13,500

The lignite briquets represented in the table were made from a good grade of lignite, low in ash, which had undergone relatively complete carbonization. It may be said, however, that in order to procure results as satisfactory care must be exercised in selecting lignite of low ash content, for in the carbonization the ash is concentrated along with the fixed carbon in the residue. If, therefore, the ash content in the raw lignite is high, it will be greatly increased in the residue, and may be so high in an impure lignite as to reduce materially the calorific value and efficiency of the briquets. Therefore the selection of low-ash lignite for briquetting purposes is of great importance.

If, however, raw lignite having a high ash content is to be briquetted, the results of the tests herein reported indicate the desirability of stopping the carbonization before it has been fully completed. By this method the light hydrocarbons are driven off, but the heavier hydrocarbons remain behind, increasing the yield of residue considerably and reducing the relative proportion of ash. The residue gives a briquet that burns with considerable flame, but it has high heat value and is, withal, an excellent fuel for general use.

A large proportion of the briquets produced at the experimental station have been made from the partly carbonized residue, and all of the tests reported in the following pages were made with this type of briquet. It contains slightly less fixed carbon and ash than does the briquet made of completely carbonized lignite, and contains slightly more volatile matter. The calorific value, however, remains nearly the same.

The results presented in the following table may be taken as representative of the bulk of semicarbonized lignite briquets, amounting to several hundreds of tons, produced at the experimental substation, and it may be said that briquets of the quality indicated are readily produced from most of the lignite coals. The table covers tests of briquets made from Montana, Colorado, Texas, and a large number of North Dakota lignites.

Results of tests of semicarbonized lignite briquets.

Sample No.	Calorific value, per pound.	Chemical analyses.				Sample No.	Calorific value, per pound.	Chemical analyses.			
		Moisture.	Volatile matter.	Fixed carbon.	Ash.			Moisture.	Volatile matter.	Fixed carbon.	Ash.
	B.t.u.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*B.t.u.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	11,642	3.85	19.08	66.82	15.25	15	....	5.38	16.70	63.82	14.10
2	12,137	4.15	17.65	64.10	14.10	16	....	4.97	14.44	64.96	15.63
3	....	5.43	18.18	62.56	13.83	17	....	4.35	12.21	67.49	15.95
4	....	4.83	15.25	64.10	15.82	18	11,926	6.18	11.35	68.13	14.34
5	....	5.55	14.45	65.55	14.45	19	....	4.80	14.09	66.01	15.10
6	....	5.80	14.87	64.48	14.85	20	....	5.65	16.27	63.80	14.28
7	....	5.72	15.48	63.08	15.72	21	....	5.12	16.76	63.92	14.20
8	11,557	6.50	22.10	59.30	12.10	22	....	4.78	14.66	65.90	14.66
9	....	6.65	17.77	62.80	12.78	23	....	5.08	17.04	63.65	14.23
10	....	6.30	16.21	64.39	13.10	24	11,599	5.85	12.20	67.38	14.57
11	....	6.05	15.21	64.69	14.05	25	12,024	4.83	12.22	67.50	15.45
12	11,981	3.90	15.83	64.77	15.50						
13	11,669	3.57	16.23	65.03	15.17	Average.	11,692	5.25	15.70	64.51	14.54
14	....	5.97	16.25	63.46	14.32						

COMPARATIVE BURNING TESTS OF BRIQUETS.

In many practical burning tests the lignite briquets have been compared with anthracite coal and the best grades of Youghiogheny soft coal. The lignite briquets have been used under boilers and have proved an excellent and economical steaming fuel. They have been used in hot-air and hot-water heating plants with excellent results. They make a pleasing grate fire, much easier to control than one made of either hard or soft coal. In the kitchen range they have proved particularly satisfactory; they are easily kindled and produce a high heat with a slight flame which is free from soot, leaves the stove and lids clean, and produces an excellent fire for cooking and baking. They hold the heat well, last over night, and can be controlled readily by operating the grates and drafts. They have burned with excellent results in the direct-draft heating stove and self-feeding base-burner hard-coal stove.

EQUIPMENT USED IN TESTS.

In order to determine the practical value of lignite briquets as compared with anthracite coal, and as compared with raw lignite, a number of carefully conducted stove tests were made. The direct-draft stove was one of special design. It included a reservoir for evaporative purposes, which could be closed by a sliding jacket to prevent any modification of results from the atmosphere of the room. The hard-coal stove used was a standard type of self-feeder of medium size and small feed diameter. In the selection of the stove and in the conducting of the tests the ruling consideration was the objects to be obtained, which were to determine the total heat produced by briquets and the length of time of their burning, whether they would feed satisfactorily from a self-feeding stove in which the magazine was of small diameter and whether the fire could be easily controlled and kept, and to throw light on other problems associated with the practical use of the briquets in ordinary stoves. These stoves were set up in a small room in the basement of the school of mines building. The size was about that of an ordinary house stove. The room was an inside one, well protected from changes in temperature.

Special control of drafts and pipes was provided, and arrangements were made so that the temperature and flow of air through the stove and pipe could be determined at frequent intervals. The temperature of the room was uniform in all the tests, and records were made every 15 minutes during the tests. The briquets and anthracite coal were burned under exactly the same conditions and the same quantity of each fuel was used in each test.

TABULATED RESULTS OF TESTS.

Averaged results of the tests were as follows:

Results of heating-stove tests.[a]

Item.	Anthracite coal.	Lignite briquets.
Coal fired .... pounds..	45	45
Time fire lasted .... hours..	19	25
Unburned coal on grate .... pounds..	6.00	0.125
Ash in pan .... do....	7.438	8.063
Fixed carbon in ash .... per cent..	43.55	3.65
Fixed carbon in ash .... pounds..	3.239	.294
Gross heating value .... per cent..	100	126.1
Heating value, all material passing through grate assumed to be completely burned .... per cent..	100	109.7

[a] The results are averages of all the tests.

Results of evaporation tests.[a]

Item.	Anthracite coal.	Lignite briquets.
Coal fired .... pounds..	15	15
Time fire lasted .... hours..	5¾	5½
Evaporation at stove top .... pounds..	13.875	16.813
Total evaporation from and at 212° F .... do....	16.156	19.532
Unburned coal on grate .... do....	2.875	0.125
Ash in pan .... do....	4.563	2.500
Gross heating value .... per cent..	100	104.9
Heating value considering all fuel including that left on grate to have burned, per cent	183.6	132.1

[a] The results are averages of all the tests.

Results of fuel tests, showing comparisons of available heat and calorific values.

Name of fuel.	Available heat.			Calorific value.		
	Degree—hours per pound.[a]	Percentage of available heat of anthracite taken as 100.	Percentage of available heat of briquets taken as 100.	Heating value per pound.	Percentage of calorific value of anthracite taken as 100.	Percentage of calorific value of briquets taken as 100.
		Per cent.	*Per cent.*	*B. t. u.*	*Per cent.*	*Per cent.*
Anthracite	14.76	100.00	115.04	13,500	100.00	117.39
Lignite briquets	12.83	86.25	100.00	11,500	85.18	100.00
Lignite containing 20 per cent moisture	5.75	38.89	44.74	9,000	66.66	78.26
Lignite containing 30 per cent moisture	4.88	33.06	38.04	7,800	57.78	67.83

[a] Rise in temperature in degrees centigrade times the time in hours.

The results of the tests are also indicated in the curves shown in figures 3, 4, and 5.

COMMENTS ON THE RESULTS.

The tests showed that the briquets did not require as much draft as did the anthracite coal.

The excellent showing made in the actual stove tests was due in a large measure to the fact that the lignite briquets, although having only about twelve-thirteenths the calorific value of anthracite when burned in a stove were completely consumed, leaving no unburned carbon on the grates or in the ash as did the anthracite. This is clearly seen by comparing the carbon in the anthracite ash with that in the lignite-briquet ash. It will be seen that the anthracite ash with its little fragments of carbonaceous partly burned clinker contained about 13 times as much unburned carbon as did the lignite-briquet ash.

The table last preceding indicates the low efficiency obtained in the actual burning of lignite as ordinarily mined and marketed, a condition in which it is shown to have an efficiency less than one-third that of anthracite and only a little more than one-third that of briquets. Moreover, there is much additional labor and inconvenience caused by handling and burning three times as many tons of lignite of large lumps in so greatly varying size.

The curves plotted in figure 5 show the characteristic rapid rise and fall of the ordinary lignite fire as contrasted with the gradual rise and prolonged continuation of the fire made of briquets.

COMPARATIVE BOILER TESTS OF BRIQUETS.

In order to prove the relative value of lignite briquets (semicarbonized) for steaming and power purposes, the briquets have been used under numerous types of boilers with excellent satisfaction.

The table following gives the results of carefully conducted evaporative tests made with the same boiler, by the same fireman, and under as nearly as possible identical conditions, lignite semicarbonized briquets and Youghiogheny soft coal being used alternately. The boiler used was of the return tubular type, 16 feet long and 66 inches diameter, with 66 $3\frac{1}{2}$-inch tubes. The grates were stationary and of the herringbone type, with $\frac{1}{2}$-inch openings and a grate surface $4\frac{1}{2}$ by $5\frac{1}{2}$ feet. The table follows:

Results of boiler tests of lignite briquets and soft coal.

Item.	Lignite briquets.	Youghiogheny coal.
Heating surface of boiler ... square feet	1,175	1,175
Grate area ... do	24.75	24.75
Ratio of heating surface to grate area	48.1	48.1
Average steam pressure ... pounds	114.2	115
Average temperature of feed water, ° F	65	65
Fuel used per hour ... pounds	381.8	380.2
Fuel used per hour per square foot of grate area ... per cent	15.4	15.35
Fuel used per horsepower-hour ... do	3.76	3.88
Proportion of ash in fuel ... do	10.76	8.84
Proportion of clinker ... do	0.93	4.11
Proportion of combined ash and clinker ... do	11.69	12.95
Actual quantity of water evaporated per hour ... pounds	2,931.9	2,838
Actual quantity of water evaporated per square foot of heating surface per hour, pounds	2.49	2.41
Actual quantity of water evaporated per pound of coal ... pounds	7.68	7.46
Quantity of water evaporated per hour, from and at 212° F ... do	3,503.3	3,380
Quantity of water evaporated per square foot of heating surface per hour, from and at 212° F ... pounds	2.98	2.89
Quantity of water evaporated per pound of coal, from and at 212° F ... do	9.18	8.88
Average boiler horsepower developed	101.5	98

Lignite briquets gave good satisfaction in the various kinds of burning tests to which they were put. They burned with an even fire and with a gentle, smokeless flame, gradually burning from circumference to center. They showed no signs of disintegration during the burning. They stood poking and shaking satisfactorily. The unburned parts of the briquets remained hard and strong until entirely consumed. In several tests briquets were taken from the fire and while still red-hot were immersed in cold water. The severe treatment produced no appreciable effect, as they remained hard and did not disintegrate or even crack.

They burned on the grate perfectly, leaving no unburned lumps such as are left in the burning of ordinary coal. The ash is fine and granular, readily sifts through the grates, and contains only a trace of unburned coal or carbon. In this respect the lignite briquets are remarkable, as shown by the analyses of the ash from anthracite coal and from lignite briquets. The anthracite ash contained 43.5 per cent unburned combustible matter, whereas the lignite ash contained only 3.6 per cent.

An analysis was made of the ash from each test to determine the proportion of combustible matter. The proportion in the anthracite coal ash will be seen to have been considerable, but there is almost no combustible matter left in the ash from the briquet. This is one reason why in the actual burning tests lignite briquets gave such high efficiency.

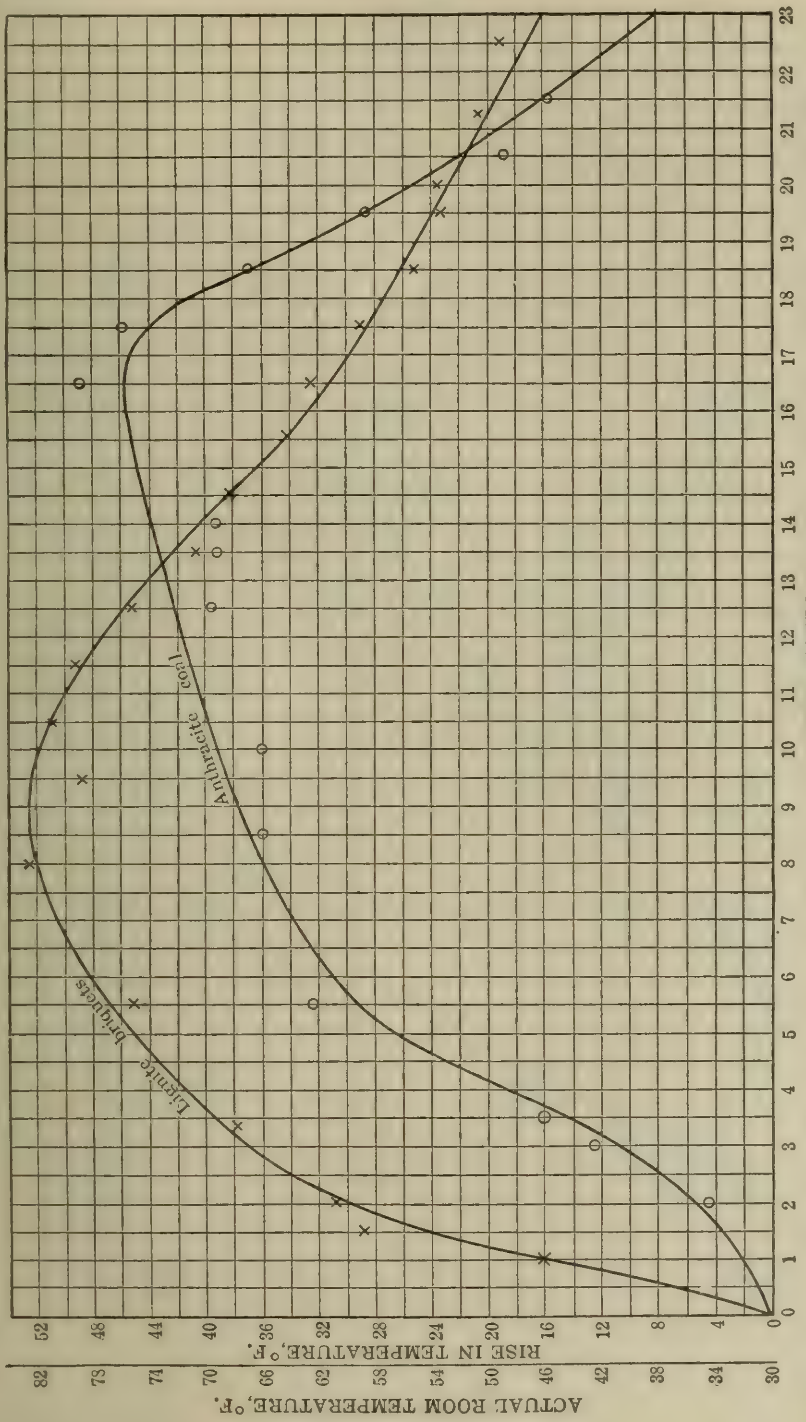


FIGURE 3.—Curves showing relative heat values obtained by burning lignite briquets and anthracite coal in self-feeding, base-burner, hard-coal stove.

SUMMARY.

To one thoroughly familiar with the great extent of the Western lignite deposits, their limited development, and the comparatively simple methods that have thus far been adopted in their utilization as fuel, any investigations looking to a possible and increased utilization of these vast deposits must at once be considered of great economic importance. There is no doubt but that much can be done toward improving the methods of burning now in use, and in providing means for using the coal in other forms, such as in a pulverized state, or in the manufacture of producer gas, or of by-product gas, or as residue briquets. Especial attention has been given by the writer to the study of utilizing the lignite in the form of residue briquets and in the manufacture of by-product gas, because in this

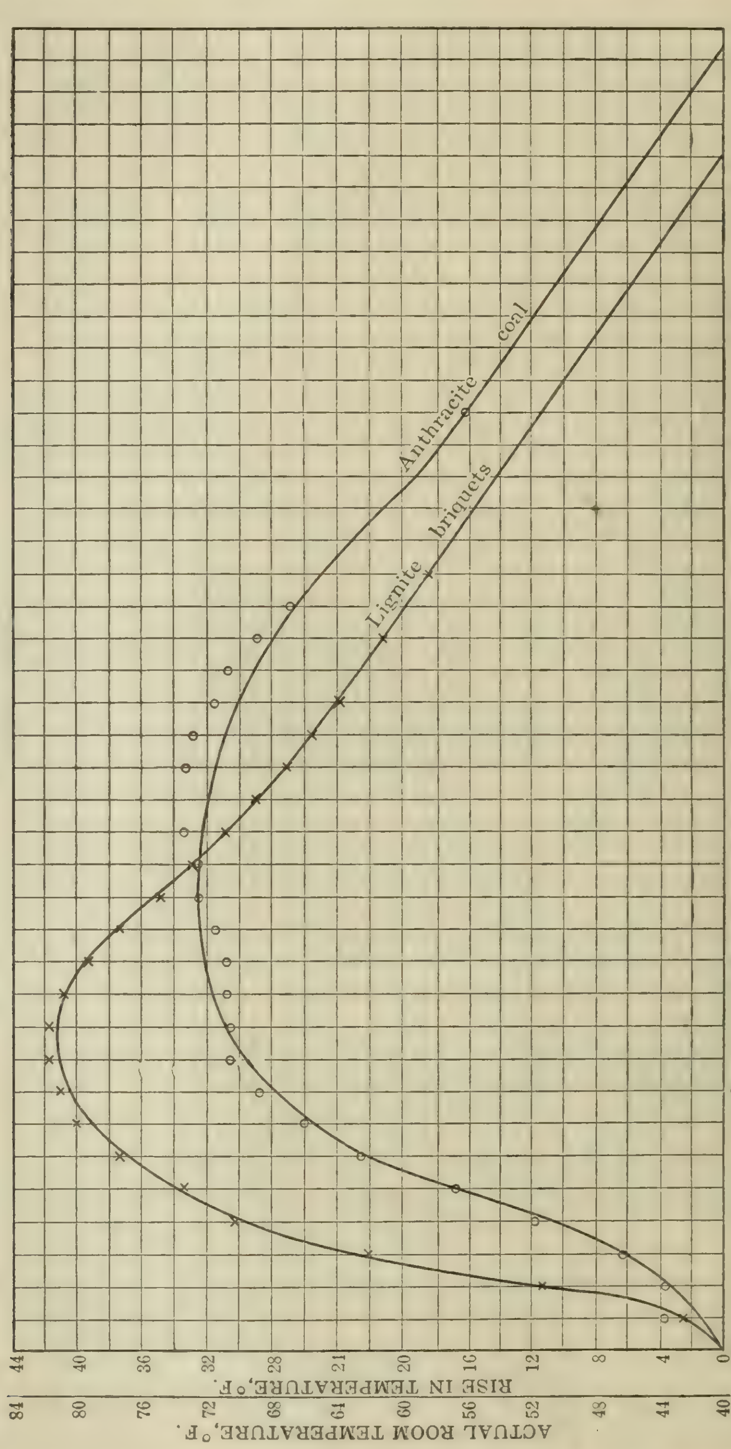


FIGURE 4.—Curves showing relative heat values obtained by burning lignite briquets and anthracite coal in a direct-draft stove.

method there appear excellent possibilities of providing a satisfactory and efficient fuel and of recovering numerous by-products.

From the results obtained by the methods being developed at the school of mines and the substation of the University of North Dakota there seems little doubt but that the briquetting and the

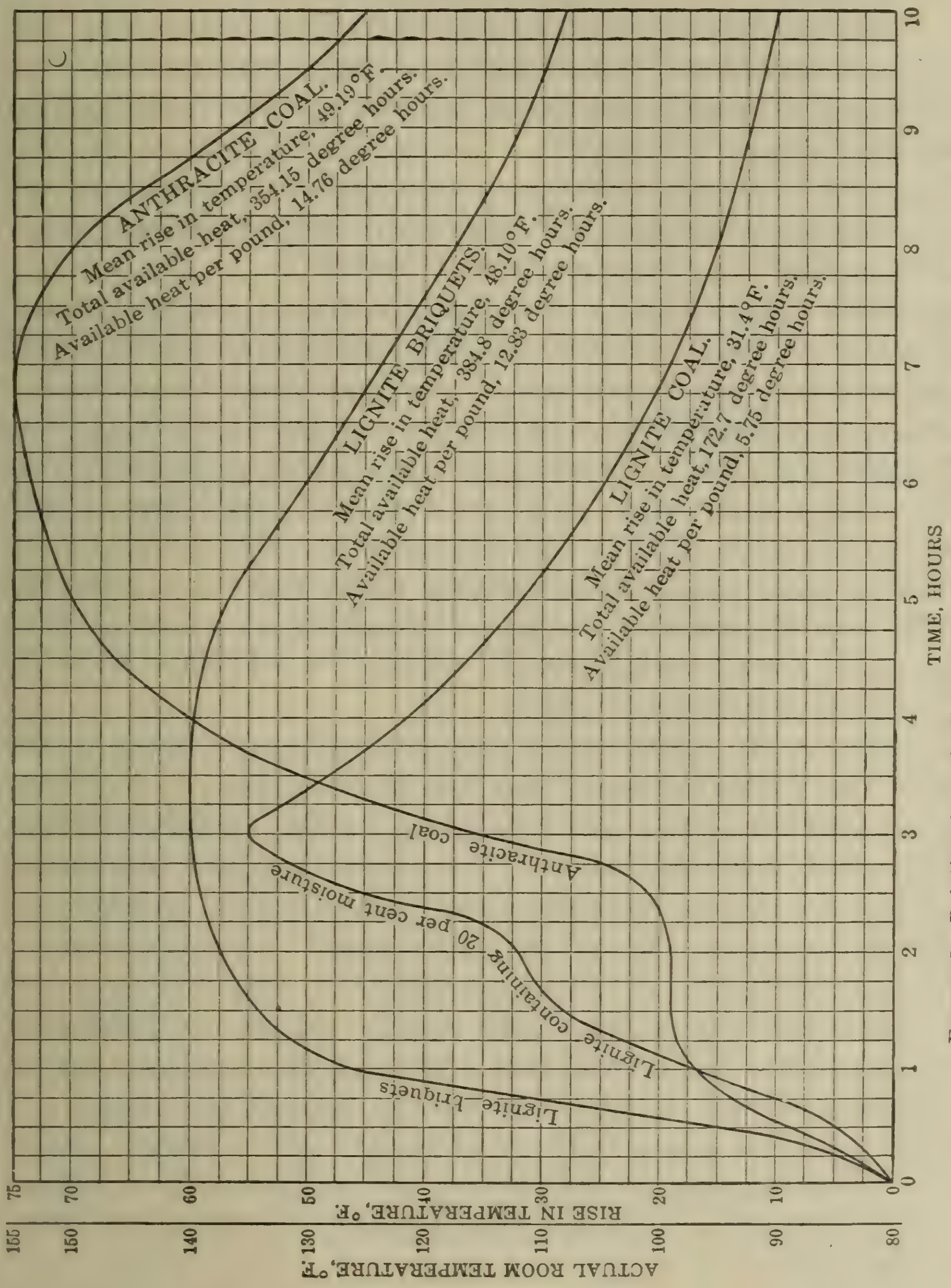


FIGURE 5.—Relative rise and fall of lignite, lignite-briquet, and anthracite fires.

production of gas from lignite can in the near future be put on a commercially satisfactory basis.

Because of the ease with which the gas is produced, the low price of the original lignite, the value of the residue, and the low price for which it could be sold if manufactured in a plant used to produce briquets from the residue, the lignite gas should have a large commercial utilization for heating, lighting, and power purposes. It has been found that briquets made from this concentrated residue produce a most excellent fuel, for all practical purposes approaching the efficiency of anthracite. One ton of the air-dried lignite will produce from a half to two-thirds of a ton of briquets in addition to 8,000 or 10,000 cubic feet of gas. The briquets have about twelve-thirteenths the actual heating value of hard coal, and they can be shipped for considerable distances and still prove profitable. The briquets present many advantages, especially over the original lignite as usually placed on the market. The heating value is nearly doubled, the briquets do not disintegrate on standing or burning, they can be stored without being affected by atmospheric conditions, they are uniform in size and are convenient to handle.

No detailed statements of the cost of operating a large commercial plant are given in this report for the reason that the cost per ton of briquets and per 1,000 feet of gas and other by-products will depend upon a large number of factors, any one of which may materially affect the cost. For example, the cost of production is much less in a large plant than in a small one, and also less in a plant favorably situated—that is, near a mine, a city, and railway facilities. The use of mine slack, the percentage of moisture in a given lignite deposit, and the relative cheapness of mining and ease of delivery to the plant are all variable conditions and would have to be determined for each individual plant.

In addition the plant could be operated under many modifications of the general process that has been explained; for example, all or a part of the gas might be sold for heating or lighting purposes or converted into electricity. The extraction and production of gas might be carried further in one plant than in another, or the by-products, such as tar and ammonia, could be recovered and marketed, used in part, or entirely neglected. Differences in any of these conditions would materially modify the cost of production.

In general the larger the plant and the more complete the saving of by-products the smaller will be the cost of production. It is believed that in a carefully constructed and operated plant the saving and utilization of the various by-products will so reduce the cost of operation as to make the industry commercially practical and profitable.

All of the data obtained from the investigations and the operation of the experimental plant indicate that a plant of fair capacity, if so constructed as to economize in the original cost, as well as in the cost of operation, and if operated efficiently and under careful management, should turn out excellent commercial products at a cost that would admit of a fair profit.

In order to establish the industry successfully great care should be taken in planning and operating the plant, and the methods employed should follow very closely those that have proved satisfactory in the experimental work, the principles of which are outlined in this report.

Although the general principles involved in the process explained in this report are not complicated, the proper observance of the many details of operation is essential to success, and those managing and operating the plant should have had technical training and experience.

The development of methods for the utilization of low-grade coal will prove of much value to those communities nearest the great lignite deposits in the West. In some of these the lignite could be converted into electricity, which in turn could be sent to surrounding towns and villages, thus distributing power and light from numerous central power plants. Such an arrangement would not only be a great saving of our fuel resources but would also result in the establishment of many industries that can be developed by abundant and cheap electric power.

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